A HEYWOOD PUBLICATION

British Chemical Engineering

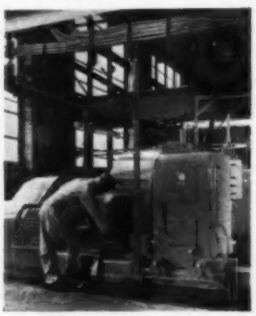
THE JOURNAL DEVOTED TO THE TECHNIQUES OF CHEMICAL ENGINEERING APPLIED TO INDUSTRY

SEPTEMBER 1960
Vol. 5 No. 9

Editor:
J. O. S. MACDONALD, B.Sc., M.I.Chem.E., A.R.I.C.

Associate Editor:
I. BERKOVITCH, Ph.D., F.R.I.C., A.M.I.Chem.E.

Assistant Editor:
DAVID V. MARTIN, B.Sc.



The front cover shows a Broadbent type 80 automatic ploughing centrifuge with hydraulically retracted plough head. (Photo by courtesy of Thomas Broadbent and Sons Ltd., Huddersfield.)

Classified Advertisements, after page 610

BRITISH CHEMICAL ENGINEERING is published monthly by HEYWOOD & CO. LTD., Drury House, Russell Street, Drury Lane, London, W.C.2 (Tel.: TEMple 3422), on the 20th of the preceding month. Annual subscription £2 U.K., £2 10s. 0d. sterling overseas for 12 issues post free ($7.50 U.S.A. and Canada) or by standing order through newsagents at 2s. 6d. a copy net. BRANCH OFFICE: Royal Buildings, 2 Mosley Street, Manchester, 2. Tel: Central 9935. © Heywood & Co. Ltd., 1960. Must not be reproduced without written permission.

MAIN ARTICLES

Automatic Control of Centrifugals *by F Broadbent, F.R.S.A., B.Sc., M.I.Chem.E., and G. L. Grimwood, B.Sc.(Eng)., A.M.I.E.E., A.M.I.Mech.E.* 614
Contrôle automatique des appareils centrifuges
Automatische Zentrifugenregelung
Автоматический контроль центрифуг

Thermal Dehydrochlorination of Ethylene Dichloride *by L. K. Doraiswamy, P. H. Brahme, M. U. Pai and S. Chidambaram* 618
L'élimination thermique de l'acide chlorhydrique du dichlorure d'éthylène
Die thermische Entziehung von Chlorwasserstoff aus Äthylendichlorid
Термическая дегидрохлорнация этиленового двухлорида

Adsorption Drying of Gases Part III *by J. W. Carter, B.Sc., F.R.I.C., A.M.I.Chem.E.* 625
Le séchage des gaz par adsorption — 3ème partie
Adsorptionstrocknen von Gasen — Teil III
Высушивание газов путем адсорбации—3ья Часть

The Relationship between Duty and Size of a Cooling Tower *by F. H. H. Valentin Ph.D., M.I.Chem.E.* 633
Le rapport entre le travail et les dimensions des tours de refroidissement
Die Beziehungen zwischen der Aufgabe und Grösse von Kühltürmen
Соотношение между полезным действием и размером башенных холодильников

Cost of Utilities and Services *by R. S. Bickle, B.A., A.M.I.Chem.E.* 636
Coût des services ancillaires
Kosten der Öffentlichen Versorgung
Стоимость обслуживания установок

Flow Coefficient of Pipe Constrictions *by T. H. Redding, M.Sc., F.Inst.P., A.M.I.Mech.E.* 640
Le coefficient d'écoulement aux constrictions tubulaires
Der Fehlerkoeffizient in Rohreinengungen
Коэфициент течения в трубных сжатиях

The Training of Powder Technologists in Great Britain *by H. E. Rose, D.Sc.(Eng.), Ph.D., M.I.Mech.E., M.I.C.E.* 645
La formation des technologues des poudres en Grande-Bretagne
Die Schulung von Metallkeramikern in Grossbritannien
Обучение технологов порошковой металлургии в великобритании

OTHER FEATURES

Leader: Birthday at Warren Spring 613
Releasing Pressure in a Container to Atmosphere 617
An Automatic Backwashing Centrifuge 624
Rotary Dryers for Iron Ore Plant 631
Silicon-Aluminium Steels 632
A New Fumaric Acid Process 635
Sealing against Pressure and Vacuum 652
Nomogram No. 51 The equivalent diameter for heat exchanger tube bundles 660

REGULAR FEATURES

Digest 603
Process Engineer's Notebook 662
Book Reviews 664
Plant Equipment News 666
World of Chemical Engineering 676

Résumés

B.C.E., 5, 9, 614. U.D.C. 621-52:66.067.5: 621.928.3.

CONTROLE AUTOMATIQUE DES APPAREILS CENTRIFUGES

par F. Broadbent et G. L. Grimwood

Le contrôle des différentes phases d'une opération centrifuge est obtenu au moyen de commandes agissant dans un ordre ou dans un temps déterminés. Le contrôle de l'alimentation est particulièrement important et peut se réaliser au moyen de méthodes qui dépendent du caractère de la suspension, de la vitesse, de la sécurité et du site. Les auteurs étudient, entre autres, le cas des appareils centrifuges pour le traitement du sucre.

B.C.E., 5, 9, 618. U.D.C. 66.094.6:661.723.622.

L'ÉLIMINATION THERMIQUE DE L'ACIDE CHLORHYDRIQUE DU DICHLORURE D'ÉTHYLÈNE

par L. K. Doraiswamy, P. H. Brahme, M. U. Pai, S. Chidambaram

La cinétique et la thermodynamique de la décomposition thermique de la réaction sont étudiées par les auteurs. Ils suggèrent deux équations pour le taux de conversion générale du dichlrorure d'éthylène ; la première, pour les conversions allant jusqu'à 80%, la seconde pour les conversions de 80% à 100%. Ils présentent une corrélation approximative permettant d'estimer cette conversion ; cette corrélation représentent les données expérimentales avec une déviation moyenne de 2%.

B.C.E., 5, 9, 625. U.D.C. 66.074.327.

LE SÉCHAGE DES GAZ PAR ADSORPTION — 3ème PARTIE

par J. W. Carter

L'auteur examine en détail la construction de sécheuses par adsorption à lits fixes et compare les résultats prévus par les méthodes décrites dans la seconde partie aux résultats pratiques observés avec les appareils à adsorption. On constate que la méthode due à Rosen, qui tient compte des importants mécanismes du séchage, est la plus utile. L'auteur examine également la réactivation, les températures minima des lits, l'effet de la présence de gaz adsorbables sur le rendement du séchage, et le dessin des appareils d'adsorption à lits fluides.

B.C.E., 5, 9, 633. U.D.C. 66.045.54.

LE RAPPORT ENTRE LE TRAVAIL ET LES DIMENSIONS DES TOURS DE REFROIDISSEMENT

par F. H. H. Valentin

L'article présente une nouvelle méthode de calculs pour les tours de refroidissement et autres cas de transfert massif. Il s'agit de la Méthode de la Moyenne Logarithmique d'Enthalpie, qui est basée sur la nature presque parabolique de la courbe température-enthalpie de l'air saturée d'humidité. On peut se servir de cette méthode pour d'autres calculs de transfert massif, à condition que la courbe d'équilibre puisse être rendue par un polynome de second ordre. La précision est excellente et la méthode ne demande pas l'emploi d'une calculatrice.

B.C.E., 5, 9, 636. U.D.C. 66.013 7:657.47.

COÛT DES SERVICES ANCILLAIRES

par R. S. Bickle

L'article aidera la personne responsable de l'estimation des frais de production en lui donnant le coût d'un certain nombre de services ancillaires utilisés dans les usines de produits chimiques. Ces services comprennent la fourniture en gaz inerte, vapeur, air comprimé, électricité, réfrigération et divers types d'eau, dont l'eau destinée aux tours de refroidissement.

B.C.E., 5, 9, 640. U.D.C. 532.542:681.121.8: 66.026.

LE COEFFICIENT D'ÉCOULEMENT AUX CONSTRICTIONS TUBULAIRES

par T. H. Redding

Grâce au traitement unidimentionnel étendu de l'écoulement à travers un rétrécissement tubulaire, l'auteur a pu établir une formule donnant le coefficient d'écoulement qui tient compte de la courbure des courants. Il utilise cette formule pour expliquer le caractère du coefficient d'écoulement pour diverses constrictions servant aux mesures. L'auteur incorpore des facteurs de correction pour tenir compte des effets des facteurs qui déterminent la forme de l'écoulement.

Kurzreferate

B.C.E., 5, 9, 614. U.D.C. 621-52:66.067.5: 621.928.3.

AUTOMATISCHE ZENTRIFUGENREGELUNG

von F. Broadbent u. G. L. Grimwood

Die Regelung von Mengenschleudervorgängen erfolgt entweder durch Folge- oder Zeitregler. Die Vorschubregelung ist sehr wichtig und lässt sich durch eine Anzahl von Verfahren besorgen, die von der Geschwindigkeitsregelung, Sicherheit, Aufstellung usw. abhängen. Der Sonderfall von Zuckerzentrifugen wird ebenfalls besprochen.

B.C.E., 5, 9, 618. U.D.C. 66.094.6:661.723.622.

DIE THERMISCHE ENTZIEHUNG VON CHLORWASSERSTOFF AUS ÄTHYLENDICHLORID

von L. K. Doraiswamy, P. H. Brahme, M. U. Pai, S. Chidabaram

Der Artikel bespricht die Reaktionskinetik und Thermodynamik der Thermalzersetzung dieser Reaktion. Zwei Geschwindigkeitsgleichungen werden vorgeschlagen, betreffend die allgemeine Transformation von Äthylendichlorid, u.zw., eine für die Konversion bis zu 80% und die andere für die Konversion zwischen 80% und 100%. Allgemeine Beziehungen werden gegeben zur Abschätzung dieser Konversion mit Experimentaldaten, mit einer durchschnittlichen Abweichung von 2%.

B.C.E., 5, 9, 625. U.D.C. 66.074.327.

ADSORPTIONSTROCKNEN VON GASEN — TEIL III

von J. W. Carter

Die Konstruktion von festgepackten Adsorptionstrocknern wird in Einzelheitenbesprochen und die durch die Methoden des 2. Teils vorausgesagten Ergebnisse werden mit praktischen Resultaten verglichen. Rosens Methode, welche die wichtigen Mechanismen der Trocknungsverfahrens in Betracht zieht, scheintdie nützlichste zu sein. Reaktivierung, mit Einschluss der Mindesttemperaturen des Betts, die Wirkung von adsorptionsfähigen Gasen auf die Trocknung und die Konstruktions des Flüssigbettadsorbers sind ebenfalls besprochen.

B.C.E., 5, 9, 633. U.D.C. 66.045.54.

DIE BEZIEHUNGEN ZWISCHEN DER AUFGABE UND GRÖSSE VON KÜHLTÜRMEN

von F. H. H. Valentin

Eine neue Methode zur Berechnung von Kühltürmen und anderen Massenübertragern, die korrekte Durchschnittslogarithmus-Enthalpie-Methode, benützt die fast parabolische Natur der Temperatur-Enthalpie Kurve für feuchte, gesättigte Luft. Die Methode lässt sich auch für andere Massenübertragungsberechnungen verwenden, wenn die Gleichgewichtskurve durch ein Polynom zweiter Ordnung angenähert werden kann. Die Genauigkeit ist ausgezeichnet und die Methode benötigt keine Rechenmaschine.

B.C.E., 5, 9, 636. U.D.C. 66.013 7:657.47.

KOSTEN DER ÖFFENTLICHEN VERSORGUNG

von R. S. Bickle

Ein Voranschlagsrechner gibt die Kosten der von der Chemieindustrie benötigten Dienste und Versorgungen. Diese umfassen die Anlieferung von inerten Gasen, Dampf, Druckluft, Elektrizität und verschiedene Arten von Wasser, mit Einschluss von Wasser für Kühltürme.

B.C.E., 5, 9, 640. U.D.C. 532.542:681.121.8: 66.026.

DER FEHLERKOEFFIZIENT IN ROHREINENGUNGEN

von T. H. Redding

Eine erweiterte eindimensionale Behandlung des Fehlers einer Rohreinengung führt zu einer Formel für den Fehlerkoeffizienten, der die Kurvatur der Stromlinien in Betracht zieht. Die Formel wird dazu benützt, den Charakter des Fehlerkoeffizienten für verschiedene Konstriktionen zu erklären. Korrekturfaktoren ermöglichen die Inbetrachtziehung von Faktoren, welche den Fehler charakterisieren.

Резюме

B.C.E., 5, 9, 614. U.D.C. 621-52:66.067.5: 621.928.3.

АВТОМАТИЧЕСКИЙ КОНТРОЛЬ ЦЕНТРИФУГ

Ф. Бродбент и Г. Л. Гримвуд.

Контроль над отдельными стадиями совокупных центробежных рабочих процессов обеспечивается или последовательным, или контролем времени. Важнее всего контролирование подачи, что можно осуществить рядом методов в зависимости от типа жидкой намойки, контроля скорости, мер предосторожности и риска связанного с местонахождением. Обсуждается в частности особый вопрос контроля сахарных центрифуг.

B.C.E., 5, 9, 618. U.D.C. 66.094.6:661.723.622.

ТЕРМИЧЕСКИЯ ДЕГИДРОХЛОРИНАЦИЯ ЭТИЛЕНОВОГО ДВУХЛОРИДА

Л. К. Дорайсвами, П. Г. Брам, М. Ю. Пай С. Чидамбарам.

Рассматривается реакционная кинетика и термодинамика термического распада реакции. Предлагаются две степени уравнения для полного преобразования этиленового дихлорида — первая для преобразования до 80% и вторая для преобразований между 80% и 100%. Приводится приблизительное соотношение, что-бы оценить эту конверсию, которая предетавляет экеспериментальные данные со средним отклонением в 2%.

B.C.E., 5, 9, 625. U.D.C. 66.074.327.

ВЫСУШИВАНИЕ ГАЗОВ ПУТЕМ АДСОРБАЦИИ 3—ЬЯ ЧАСТЬ

Дж. В. Картер

Расматривается в подробностях конструкция адсорберов — сушителей с неподвижной плитой и результаты применения методов описанных во второй части статьи сравниваются с практическими результатами адсорберов. Доказывается что метод Розена является самым полезным; этот метод учитывает важные устройства высушивающего процесса. В статье обсуждается также реактивирование, включая необходимый минимум температуры плиты, влияние наличия газов способных к адсорбции на степень высушивания и конструкция адсорберов с жидкой плитой.

B.C.E., 5, 9, 633. U.D.C. 66.045.54.

СООТНОШЕНИЕ МЕЖДУ ПОЛЕЗНЫМ ДЕЙСТВИЕМ И РАЗМЕРОМ БАШЕННЫХ ХОЛОДИЛЬНИКОВ РАЗМЕРАМИ ХОЛОДИЛЬНИКОВ

Ф. Г. Г. Валентин.

Усовершенствованный метод логорифмической средней энтальпии — новый метод для вычислений башенных холодильников и других передач массы — использует почти параболические свойства кривой температура — энтальпия для насыщенного влагой воздуха. Этот метод может быть применен для вычислений других передач массы, при условии, что кривая равновесия может приближатся к второму разряду полиномов; достигается превосходная точность и этот метод не требует применения вычислительных машин.

B.C.E., 5, 9, 636. U.D.C. 66.013 7:657.47.

СТОИМОСТЬ ОБСЛУЖИВАНИЯ УСТАНОВОК

Р. С. Бикл.

Справочник для высчитывания стоимости разных установок, необходимых на химическом заводе. В это число входят — инертные газы, пар, сжатый воздух, электричество, рефрижирация, и различные виды воды, в частности воды башенных холодильников.

B.C.E., 5, 9, 640. U.D.C. 532.542:681.121.8: 66.026.

КОЭФФИЦИЕНТ ТЕЧЕНИЯ В ТРУБНЫХ СЖАТИЯХ

Т. Г. Реддинг.

Продолжительная едино-пространственная обработка течения через сжатие в трубе позволяет установить формулу коэффициента течения, которая учитывает изгиб линии струи. Эта формула применяется для обяснения вида действительного течения для различных подсчётных сжатий. Вводятся исправительные факторы, что-бы дать возможность действия факторам определяющим линию течения.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Guidance on Chemical Plant Instrumentation

IT is probably the smaller firm that is likely to gain most from a new publication by the Association of British Chemical Manufacturers. Written primarily for managers and technicians whose knowledge of instruments may be limited, this modest booklet makes no claim to guide the specialist engineers who would be available in the large organisations. Within this clearly defined framework, there are surveys of methods for measuring pressure, steam flow, smoke density, pH and temperaure by thermocouples. Analytical instruments are dealt with in a general article followed by detailed ones on gas chromatography, non-dispersive infra-red gas analysers and flue gas analysers for small boilers. Each article is followed by a short bibliography. When these notes were first circulated in typescript they created such interest that the Productivity Committee of the Association decided to re-issue them in the present more permanent form*.

In general, the material appears to us to have hit just the right level and treatment for the non-specialist in industry who is the intended reader. We particularly liked the article by MR. J. D. TALLANTIRE of I.C.I. on analytical instruments for process use. This might usefully have been extended and used as a formal introduction to the other articles on analysis, for it starts at rock bottom by asking why these instruments should be used on a plant. After discussing the instruments available MR. TALLANTIRE has examined the difficulties in plant application. Finally there are suggestions on the considerations in selecting an intrument. These may not actually carry the user to the point of decision but they should at least enable him to discuss the matter in an informed way with the instrument manufacturer.

* Chemical Plant Instrumentation. Some Notes on the use of Measuring Instruments. Association of British Chemical Manufacturers, Strand, London, W.C.2. 1960. 6s. members; 7s. 6d. non-members, post free.

New Approach to Separating Aromatics from Petroleum Mixtures

MIXTURES of paraffins, naphthenes and aromatics, as encountered in the petroleum industry, exhibit highly non-ideal phase behaviour. By applying the theory of solutions to the non-ideality of paraffin-aromatic mixtures, E. L. EKHOLM has suggested a simplified approach which permits estimation of volatility data for their separation calculations. For mixtures of dissimilar molecular types, such as mixtures of paraffins and aromatics, corrections for deviation from the gas law can be insignificant in comparison with the non-ideal behaviour of the liquid phase. This liquid phase non-ideality is ordinarily investigated in the laboratory by accumulating vapour liquid equilibria data for binary combinations of various paraffins, naphthenes and aromatics. Liquid phase non-ideality is ordinarily expressed in terms of activity coefficients. The Margules and the van Laar equations are two of the common methods of correlating these with concentrations of components in a binary system.

However, MR. EKHOLM suggests that the "internal pressure" of a component—the energy of vaporisation divided by molal volume—can be used directly as a criterion of its compatibility with other components in a mixture; when components have markedly differing internal pressures, their volatility relations will deviate markedly from ideal behaviour. Internal pressure is a descriptive term for the thermodynamic relationship. The name is derived from the relationship of the terms in equations of state. In the van der Waals equation, internal pressure is the difference between the thermal pressure and the external or vapour pressure. Furthermore, ATKINS and BOYER have presented a technique for approximating the internal pressure for engineering calculation purposes. By proper manipulation of the terms the internal pressure of a component in atmospheres may be computed from the expression 23 sL (s being its specific gravity, L the latent heat of vaporisation).

In a paper presented before the American Institute of Chemical Engineers at Mexico City the procedure was illustrated in the preparation of a rapid appraisal for the economic feasibility of recovering 98% pure normal hexane from a natural gasoline fraction.

Periodic Heat Flow Characteristics of Slabs

ALTHOUGH the steady-state heat flow equation provides an adequate basis for much structural design work, there are cases, such as the conditioning of tropical buildings, where the periodic variations of the outside temperature and solar radiation have to be taken into account. Recent studies of this problem by E. DANTER of the Building Research Station may well be of interest in a wider context. The main purpose of his paper* is to give for the simpler types of structure methods for determining the alternating transmittances and time-lags required in calculating heat flow under periodically varying conditions. Exact analysis requires separate consideration of the harmonic (Fourier) components of the flow, each with its appropriate transmittance and time-lag. There is, however, a simple approximate method suggested by MACKEY and WRIGHT which is sufficient to give a broad indication of the heat flow variations. This requires only the "fundamental" time-lag and "fundamental" alternating transmittance U.

MR. DANTER has gone on to carry out a statistical examination of calculated values for a range of constructions. For these cases of commonly used materials it proved possible to derive simple rules to give estimates with an accuracy of about 10% to 20%. For example, it was found that the fundamental time-lag could be taken as ten hours per foot of thickness. To obtain the fundamental alternating transmittance it was adequate to divide the steady-state U-value by factors according to the thickness. These factors are 1, 2, 4, 8, . . . for thickness 3 (or less) 7, 11, 15, . . . in. Factors for other thicknesses are obtained by interpolation.

* *Journal of the Institution of Heating and Ventilating Engineers* 1960, Vol. 28, p.136.

Cadmium Recovered From Lead Smelter Fumes as Chloride

IN a process for cadmium recovery from lead smelting fumes developed by Cia. Metalúrgica Peñoles, S.A. of Mexico no attempt is made to concentrate the metal nor are reagents added to produce a water-soluble compound. The dust containing about 5% cadmium is collected in a Cottrell plant and was noticed to contain a considerable amount of chlorine. Cadmium was thought to be present in the form of CdO and chlorine as $PbCl_2$ and $ZnCl_2$. On heating the dust above 325°C up to 80% of the cadmium became water-soluble. After considerable testing it was therefore decided to construct a plant for manufacturing cadmium based on the leaching of the soluble chloride and precipitating the metal from the pregnant solution by means of zinc dust.

MR. F. W. GIBSON, Manager of the Torreon plant, has recently described the stages of this process. Main step is the treatment at 400°C for about 8 hours in an oil-fired Godfrey roaster consisting of a rotating circular hearth or table enclosed in brickwork. This type of roaster was chosen because it gives a uniform heating of the charge due to continual mechanical raking. The feed is charged at the centre of the hearth and is raked in a spiral path towards the discharge at the periphery. A Cd : Cl ratio of 1 : 1 is required in the dust in order to obtain 66 to 70% soluble cadmium in the heat-treated product. The latter is then ground and leached with water in a ballmill and the pulp filtered. Further steps are removal of lead and arsenic from the pregnant solution by addition of $K_2Cr_2O_7$ and $KMnO_4$, removal of copper by preliminary precipitation using 4 to 5% of zinc dust and precipitation of cadmium sponge from slightly acid solution using high purity zinc dust. The sponge is dewatered and washed on a filter press, briquetted, melted under caustic cover for removal of zinc and remelted with ammonium chloride to remove the thallium as dross. It is then ready for casting into ball and stick form.

Benzene by Crystallization

PURE benzene of high crystallizing point can be produced from a fraction containing undesirable non-aromatic hydrocarbons by a number of processes based on crystallizing the benzene. This is the conclusion reached after joint research by Benzole Producers Ltd., The Coal Tar Research Association and Newton Chambers & Co. Ltd., The starting material will normally contain at least 90% of benzene. Main impurities will be thiophen, carbon disulphide, paraffins, naphthenes, unsaturated hydrocarbons and toluene. Their relative proportions will depend upon the preliminary treatment of the fraction. All the impurities except thiophen can be reduced to a low level by crystallization. Thiophen forms solid solutions or mixed crystals with benzene and must be removed by some other treatment.

Although carbon disulphide can be substantially removed by a crystallization process, the low carbon disulphide content that can be tolerated in the product may sometimes make it necessary to remove carbon disulphide by other means. Consequently a satisfactory feedstock would be a benzene fraction from a hydrorefined benzole or a defronted benzene fraction that has been given the requisite acid wash. In the process a high proportion of the benzene is crystallized by a technique involving intimate mixing of cold brine and benzene for example by the coalescence of jets within a centrifuge, the mother-liquor is removed by centrifuging and the crystals washed with brine. A diagram of a possible process is shown below.

An "operating committee" set up by the three organisations decided, after extensive experimental work and economic appraisal, that they favoured a process in which a small proportion of the crystals are subsequently thawed to wash out entrained mother-liquor. In a pamphlet* summarising the work it is stated that both the capital and operating costs for the plant would be low.

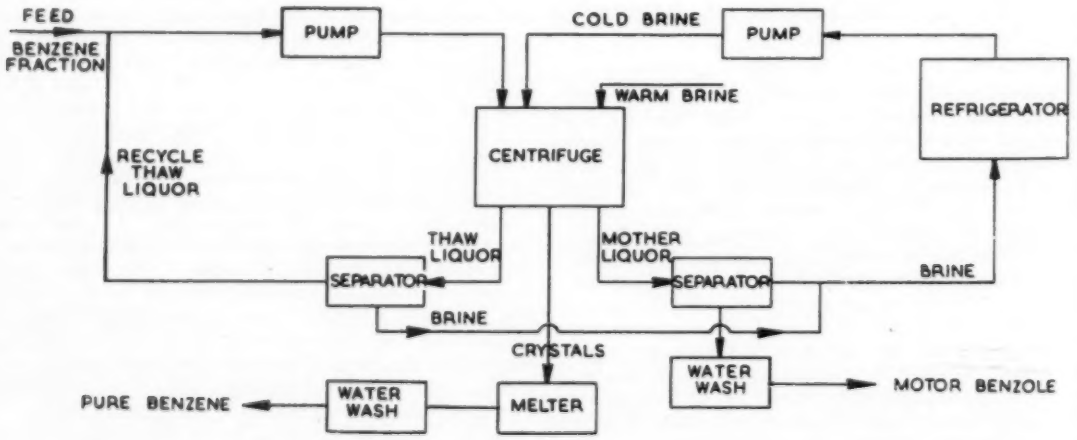
* *Crystallization Processes for the Production of Pure Benzene* by K. H. V. French, Research Paper 3—1959, Benzole Producers Ltd., 132 Sloane Street, London, S.W.1.

Limited Prospects for Gamma-Ray Sterilising of Pharmaceuticals

IT has long been considered likely that the sterilising of pharmaceutical materials would prove a useful field of application for radiations. But after a detailed study backed by a formidable list of interested organisations, a Working Party has reported* rather coolly on the prospects. The radiation source was Cobalt 60 and the work was undertaken by the Isotope Division of the A.E.R.E. It consisted of a biological investigation intended to evaluate the dose required to kill a representative selection of contaminants commonly encountered in pharmaceutical products. There was also an examination of the effect of ionising radiations on products and formulated preparations particularly thermolabile substances for which sterilisation by radiation might prove a useful alternative to existing methods. Linked with these was a cost study.

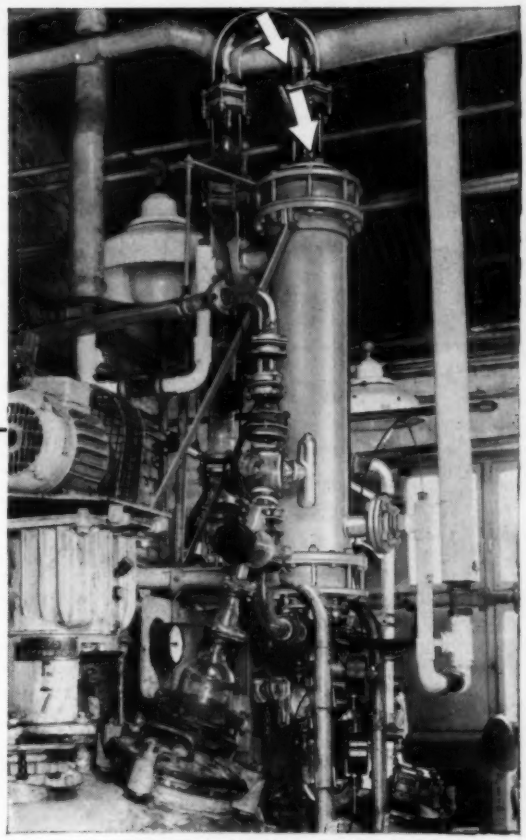
What were the conclusions?

The probable cost of sterilisation by irradiation proved difficult to ascertain but the fact that the cost per unit is dependent, to a considerable extent, on the quantity



GRAPHITE CARTRIDGE CONDENSERS

Rugged, compact, efficient; easily installed and maintained. Steel shell protected internally against weak acid solutions and externally against atmosphere. Available for heat transfer areas from 4 to 500 ft.²



20 ft.² Graphite Cartridge Condenser as used in the fine Chemical Industry.
Photograph by courtesy of British Drug Houses Ltd.

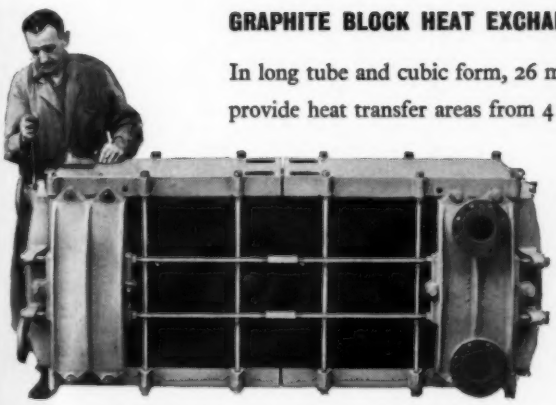
DELANIUM GRAPHITE BURSTING DISCS

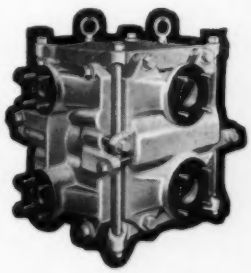
Will withstand at least 10,000 pressure applications at 75% of stated bursting pressure. A wide range of standard sizes and pressures from 1 to 400 p.s.i.g.

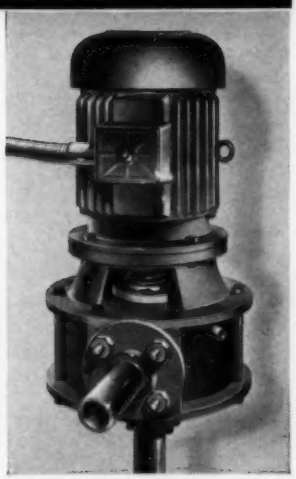
POWELL DUFFRYN
CARBON PRODUCTS LIMITED

GRAPHITE BLOCK HEAT EXCHANGERS

In long tube and cubic form, 26 models provide heat transfer areas from 4 ft.² to 500 ft.²







Delanium Graphite Vertical Centrifugal pumps for the handling of corrosive liquids.

H.P. 7901

POWELL DUFFRYN DELANIUM CARBON & GRAPHITE CARBON PRODUCTS LIMITED

HAYES, MIDDLESEX. TELEPHONE HAYES 3994

treated, was thought likely to limit application in the pharmaceutical industry. Nevertheless the radiation source might have other practical applications, for example, in controlling contamination at some stage of a manufacturing process or for the sterilisation of containers. For pharmaceuticals directly, there were disadvantages. A dose of 2.5×10^6rad appeared to be needed to achieve sterility. But this dose produces changes in many substances used in pharmacy. The extent and nature of these changes varies from product to product; in many instances the changes might render a preparation unacceptable. The group therefore decided to consider the collaborative work as completed and left it to individual members to follow up any aspects of the investigations that appeared to be of particular interest or significance.

* The Use of Gamma Radiation Sources for the Sterilisation of Pharmaceutical Products. Report of a Working Party established by the Association of British Pharmaceutical Industry, with the School of Pharmacy (University of London), and the Isotope Division, Atomic Energy Research Establishment. June 1960. Published by the Association of British Pharmaceutical Industry, London, W.C.1.

Transferring Oxygen

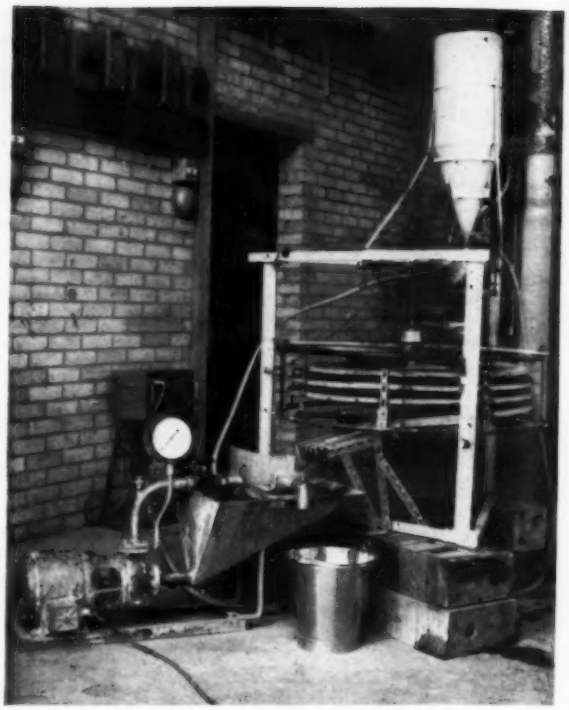
WHICH is the best way of delivering oxygen from plants—as liquid oxygen or by gas compression? A survey of this problem by D. E. SMITH is due to be presented to the Cryogenic Engineering Conference in Boulder, Colorado. The paper includes comparison of the power consumption for the two methods taking into account plant size, product delivery pressure and refrigeration cycle pressure.

Liquid pumping always requires more power overall than gas compression but the difference is less important in small plants than in large ones. In respect of pressure it is found that low oxygen delivery pressures favour the use of gas compression. Thus, large gas plants delivering oxygen at a few hundred pounds pressure should use gas compression. Liquid pumping shows to the greatest advantage in small plants making high pressure oxygen for cylinder filling and similar duties. Plants with a high pressure refrigeration cycle pay a smaller penalty for using liquid pumping than do plants with low pressure refrigeration cycles. This can be shown by examples of the difference in energy requirements for these systems. MR. SMITH concludes that the economic comparison between liquid pumping and gas compression will depend upon estimates of capital and energy requirement for specific systems. No general statement can be made as to when one may advantageously change from gas compression to liquid pumping.

In the same session of the Conference are several further papers on processes while other sessions deal with transfer phenomena, equipment, physical equilibria, heat transfer, thermometry and mechanical properties.

Recovery from Slimes by the "Shaken Helicoid"

DURING our visit to the Warren Spring Laboratory on its recent Open Day we came across a novel machine known as the "Shaken Helicoid." Developed by DR. C. R. BURCH FRS of Bristol University, it is intended for the recovery of heavy minerals from slimes such as materials having 95% of particles below 50 microns. The suspension moves down the helicoid surface which is given a movement of 3 mm amplitude and is subjected to what is called a "river bend action." Surface flow is outward due to centrifugal force and there is therefore a compensating flow inward across the bed in addition to a horizontal circular shear. The interaction yields Bagnold forces acting upwards within the suspension tending to lift small particles while the heavier ones tend to stay on the bed. There is a gutter round the edge of the surface which takes the overflow bearing lighter particles. Factors influencing beneficiation with this machine are now being studied. They include pulp concentration and frequency of vibration. Broadly the field of application appears to be in dealing with the fines rejected from other separation processes. Nevertheless its performance with Cornish cassiterite compares favourably with that of the conventional machines—the so-called Fruvanner and the Round-Frame machines—now in use. The shaken helicoid—illustrated above—has also proved successful in concentrating wolframite from Devon.



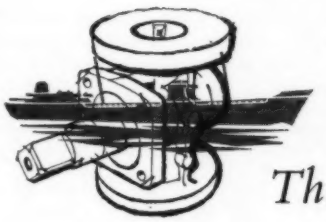
The shaken helicoid developed by DR. C. R. BURCH FRS.
Reproduced by permission of The Controller, H.M.S.O.

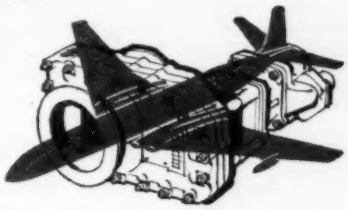
New Graphite Process?

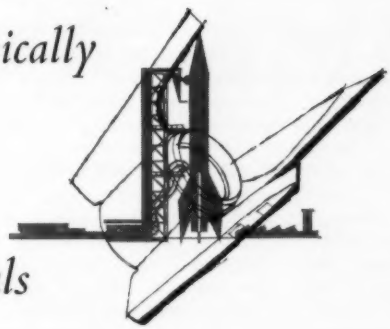
IN a graphite moulding process announced by the U.S. Atomic Energy Commission, furfuryl alcohol is used as a binder for petroleum coke and the moulded mixture heated directly to the graphitization temperature of about 5000°F. This technique, based on the fact that furfuryl alcohol yields a thermosetting resin is contrasted with that based on the use of coal tar pitch binders. Mixes based on the latter need support while being heated to temperatures of perhaps 2700°F for carbonization, since the binder passes through a liquid phase. The mix is therefore carbonised, cooled and reheated for graphitizing.

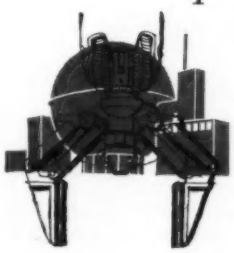
The present process announced by M. JOHN A. MCCONE, Chairman of the Commission, and developed under contract by the Armour Research Foundation of the Illinois Institute of Technology, however, bears such a striking resemblance to that developed by W. WATT and his collaborators at the Royal Aircraft Establishment, Farnborough (see *British Chemical Engineering*, Vol. 4, No. 4, p. 18) that we have drawn the attention of both MR. WATT and the Commission to the similarity. We hope to be able to report further on this as information comes to hand.

Kanigen *a hard, non-porous corrosion-resistant plate, gives complete uniform coverage even to the most intricately shaped parts. Thickness can be controlled to fine limits. Being chemically deposited Kanigen can be applied to practically all metals in commercial use. It can also be applied to non-conductors such as plastics and ceramics.*









KANIGEN
ALBRIGHT & WILSON

Approved under DTD 900/4505 and ARB A1/5112/57. Already widely used throughout industry including aircraft and nuclear applications. Kanigen is the registered trade mark of Albright & Wilson (Mfg) Ltd.

For full information write to:

ALBRIGHT & WILSON (MFG) LTD

Kanigen Department (BCE)

1 KNIGHTSBRIDGE GREEN · LONDON SW1 · TEL KENSINGTON 3422

TAW/704

New Facilities for Pulp- and Paper-making Research

TO evaluate the pulping and papermaking characteristics of a raw material it is necessary to carry out chipping, digestion, screening the pulp and beating for a range of times in a standard type of beater or mill. Following this comes sheet-formation under carefully standardized conditions from the unbeaten and beaten pulps, then conditioning and testing of the paper sheets for basis weight, bursting strength, tensile strength, tearing resistance, folding endurance. At the Forest Products Research Laboratory plans have been drawn up for a pulping laboratory and most of the equipment for digestion, screening, beating and sheet formation has now been delivered. For paper testing a room has been equipped with air-conditioning equipment and the necessary machines obtained. These preparations have followed close consultation with both the Tropical Products Institute and the British Paper and Board Industry Research Association.

Forest Products Research, 1959. HMSO 1960. 5s. 6d.

Thermodynamic Data

DESPITE the loss of its chemical engineering section, the National Chemical Laboratory continues to have a number of programmes of value to our readers. They include a major research effort on the free energies of both organic and inorganic compounds. A rotating bomb calorimeter is being constructed for those materials (such as halogen compounds) which cannot be satisfactorily burned in an ordinary bomb. A low temperature calorimeter with a high degree of automatic control, for the determination of entropies from 4°K upwards, is in the stage of design and construction. Preparations have also been made for computing entropies of gaseous compounds and vapours from spectroscopic data. In planning this programme the Association of British Chemical Manufacturers—among other bodies—were consulted for advice on the deficiencies which needed attention.

Among the physicochemical measurements now under way are those of cryoscopic constants, density, vapour pressure, second virial coefficients, latent heats of vaporization and specific heats of vapours. In addition critical temperatures of a number of organic compounds have been measured with high precision. The compounds include some normal paraffin hydrocarbons, 2-methylpentane, cyclohexene, n-propylbenzene, naphthalene and others.

Using Ideal Cascade Theory to Cost Enriched Uranium

THE costs of producing enriched uranium are determined by the cost of natural uranium and the cost of separating its isotopes. A recent report sets out a brief technical discussion of some general theoretical considerations and calculation methods involving ideal cascades for isotope separation. An ideal cascade is defined as a stagewise arrangement for isotope separation in which for each stage the downflow from the stage above and the upflow from the stage below have the same isotopic concentration, so that there is no mixing of streams of different concentrations. The document* discusses the theoretical basis for the schedule of charges for enriched uranium announced by the United States Atomic Energy Commission on November 18, 1956. Starting point is the assumption that the cost of amortizing and operating an ideal isotope separation plant is proportional to the quantity of separation work it accomplishes. After a detailed treatment of this problem, there are estimates of the reduction in the output of the top product of the cascade as a result of withdrawal of intermediate products. Further sections deal with calculating charges for U-235 burned up in reactors and determining the effects of blending uranium of different assays.

Illustrative of the level of charges reached after this careful analysis is the cost of enriched uranium in the form of UF_6 with a weight fraction of 0.10 of U-235. The official charge is 1,529.00 dollars per kilogram of uranium, that is 15.29 dollars per gram of U-235 content. The latter figure rises with the weight fraction and is 17.11 dollars per gram of U-235 content for uranium with 0.95 of U-235.

* Methods of Calculating U-235 Outputs and Charges by Use of Ideal Cascade Theory. By Artha Jean Snyder, February 1960. Office of Operations Analysis and Forecasting U.S. Atomic Energy Commission.

Equating Operations and Design

A THEME which perhaps ought not to exist was due to form the subject of a panel discussion during the Fourth Annual Heat Transfer Conference and Exhibit at Buffalo, N.Y., on August 14-17. The title was "Discrepancies between Design Procedures and Plant Operations" and the conference was sponsored by the American Institute of Chemical Engineers and the American Society of Mechanical Engineers. According to the official announcement the discussion was organised to encourage expression on what was called the unique problem of designing large scale plant and then successfully operating it. One of the aims was to find an answer to the resistance of an operations group to the incorporation of new methods into a proposed industrial process. This may at first seem more a problem in industrial psychology than chemical engineering. Yet the opposition may often be based on valuable experience. At this gathering even more than at others, frank discussion is likely to have been more useful than the formal papers and we look forward to learning more about it.

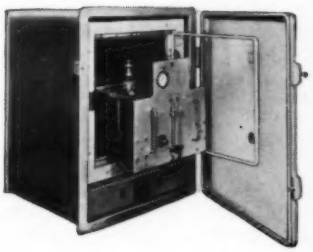
Which Way for Petrochemicals?

CRACKING of petroleum fractions at high temperature is in some degree a "blunderbuss" method compared with the precision of some syntheses. It is relatively non-selective and indiscriminate, and always produces products with a wide range of carbon number. Nevertheless this method is at the moment by far the most important route to petrochemical products. Will this always be the case?

In a recent paper* considering the impact of petrochemical development on the plastics industry, H. M. STANLEY suggests that the former will follow closely on the needs of the latter. After dealing with general cracking processes and chemical changes during refining (such as platforming) DR. STANLEY refers to the isolation from petroleum fractions of individual hydrocarbons of appropriate structures for subsequent chemical conversion. These are then subjected to direct chemical transformation to the desired product without an intermediate cracking operation. This route was expected to increase in importance in the future. It is exemplified by the production of butadiene from *n*-butane, of amyl alcohol from *n*-pentane and of nylon intermediates from cyclohexane. Other reactions likely to become of increasing importance include the vast field of hydrocarbon oxidation processes, probably the most important area of petrochemical research at the present moment, and chlorination/dehydrochlorination and dehydrogenation reactions. Furthermore numerous addition and substitution reactions of mono-olefins and butadiene, particularly those giving rise to the production of $\alpha\omega$-difunctional compounds, are of particular interest in the plastics field.

* *Transactions and Journal of the Plastics Institute* 1960 Vol. 28 No. 75, p. 110.

Process Analyser



The Pye Process Analyser is an industrial version of the well-known Pye Argon Chromatograph. By utilising an argon ionisation detector instead of a katharometer or thermistors, it achieves an outstanding performance with high sensitivity and exceptional stability. Its comparatively simple and robust design results in reliability, ease of operation and low overall cost.

The instrument draws a sample from the process stream, analyses it and presents the results on a recorder. A versatile control system selects and attenuates a number of individual peaks or gives a complete chromatogram.

The equipment, which is suitable for use in hazardous locations, is completely flexible in application. Facilities which may be supplied for individual installations include dual column analysis, multi-stream analysis, column switching, flow programming and others.

PYE ....ON STREAM!

APPLICATIONS

- ★ **PERCENTAGE ANALYSIS** of mixed hydrocarbons.
- ★ **TRACE IMPURITIES** in air, oxygen or industrial gases.
- ★ **MONITORING OF CRITICAL COMPONENTS** in a process stream.

PYE FEATURES

- ★ CONTINUOUS AUTOMATIC ANALYSIS requiring no supervision.
- ★ ULTRA-HIGH SENSITIVITIES for analysis in p.p.m. range.
- ★ CONVENTIONAL SENSITIVITIES for analysis in % range.
- ★ VERSATILITY in a wide range of applications.
- ★ COMPREHENSIVE ANALYSIS FOR LESS OUTLAY in comparison with other methods.
- ★ AIR PURGED for use in hazardous locations.
- ★ BRITISH DESIGN AND BRITISH MANUFACTURE THROUGHOUT.

W. G. PYE & CO. LTD.

Granta Works, P.O. Box 60, Cambridge, England
Telephone: CAMBRIDGE 54411 (5 lines)
Telegrams: PYE CAMBRIDGE

SCIENTIFIC PYE INSTRUMENTS

Compressed Air Regulations Extended

NEW regulations for work in compressed air came into operation on 14th August, 1960. Known as 'The Work in Compressed Air (Amendment) Regulations, 1960,'* their effect is to extend the scope of earlier ones to make them apply not only to work in compressed air carried out in works of engineering construction, but also to work in compressed air carried out in any factory or other premises or place to which the Factories Act, 1937, applies.

* S.I. 1960 No. 1307, H.M.S.O. 3d. net.

Alcohol Distillation with Inclined Tube Reboilers

A FRESH contribution to the continuing debate on the best inclination of tubes in reboilers has recently been published in *Kvasny Prumysl* (1960, Vol 6, No. 5 p. 107). BOHUSLAV MELICHAR examined the performance of reboilers manufactured according to the design of USINES DE MELLE (France) consisting of 55 copper tubes 34-30 mm diameter, 1200-1500 mm long and inclined at 30° to the horizontal working at 7 atm. pressure, distilling alcohol. Temperature in the bottom of the column was 134°C. Steam pressure in the reboiler was 3.25 atm. and the rate of producing condensate 425 kilogram/h. The reboiler was well insulated and therefore heat losses were neglected. Heating area was 6.85 sq. metres and the heat transfer coefficient found was 2853.7 Kcal/sq mh°C. In his appraisal of the reboiler with inclined tubes the author notes that the heat transfer coefficient is higher than that for horizontal tube types and pressure losses between the reboiler and the column are at minimum. Vapours rise from the reboiler directly into the column; there is no connecting piping. The tubes can be easily cleaned both inside and outside. On the other hand the reboiler with inclined tubes requires a greater floor area and is more expensive.

Pulsation Damping for Large Compressors

THIS problem has been known for many years in connection with induction systems of reciprocating air compressors and, now that free piston gas generators are becoming widely used, even more attention is being focused on this problem.

In the latter case the effects of pulsations can be particularly harmful, especially since such generators are often arranged in groups of several units with a common intake. The consequence is the occurrence of large amplitude pulsations with considerable damage potential.

DR. F. WALLACE, of Queen's University, Belfast, in a paper to be presented to the Institution of Mechanical Engineers,* examines a number of damping systems in a theoretical paper based upon the analysis of single- and two-tank systems. Using mechanical vibration theory, he discusses four single- and three two-tank damping systems in order of increasing complexity.

The author evolves a design procedure for actual systems, involving energy dissipation or systems of more complicated geometry, including filter chambers or tuning pipes, but which does not apply if the system is near resonance and he concludes that the two-tank damping system is superior to a single-tank system since, for the same performance, it has a smaller total volume, and the higher harmonics of the suction pulse are attenuated much more severely than in the single-tank system.

The fact that extensive model tests and some full-scale work have confirmed DR. WALLACE'S theoretical analysis, inspires confidence in the use of his theoretical analysis for design purposes.

* "The Chartered Mechanical Engineer," June, 1960, Page 297.

Auxiliary Equipment for Low Shaft Furnace Research

THERE is rising interest in what are called "low shaft" furnaces—essentially blast furnaces in which the stack height is drastically reduced. These permit the use of weaker coke and a smaller-sized charge than in the orthodox design and are particularly suitable where the blast is enriched with oxygen. For an internationally controlled experimental low shaft furnace Huntington, Heberlein & Co. Ltd. are now to build a special sinter plant. This will be a complete installation in miniature having an output rate of 10 tons per hour of finished sinter. It will incorporate facilities for crushing coke to $-\frac{1}{4}$in, controlling all mix ingredients with constant weight feeders, and felletising of the raw mix with a conditioning drum. Other features will be a 3 ft 6 in seven windbox machine, hot sinter creening and a forced draught cooler. The plant will be used in connection with research work by La Comité Internationale de Recherche Metallurgique at Liège, Belgium, and is expected to be commissioned in March, 1961.

DIARY

The Institution of Chemical Engineers
Graduates and Students Section

September 18-October 1. Overseas Industrial Tour, based on Paris.

European Federation of Chemical Engineering

October 2-5. Twenty-eighth meeting at Mannheim.

British Conference on Automation and Computation
Symposium on Automatic Control

September 27. In London, at the Institution of Mechanical Engineers.
- Linear and sampling systems.
- Optimum and multivariable systems.
- Systems for random inputs and disturbances.
- Self-optimizing systems.

September 28. In London, at the Institution of Mechanical Engineers.
- Position and speed controls (components and systems).
- Industrial applications (steelworks and engineering).
- Industrial applications (processes).
- Telecommunications and information processing.

Royal Swedish Academy of Engineering Science
Swedish Association of Technical Physicists

September 13-15. Fifth International Instruments and Measurements Conference, Stockholm, Sweden.

Society of Chemical Industry
Surface Activity Group

September 29-30. At the Royal Institution, Albemarle Street, London, W.1. Symposium "Powders in Industry: Properties and Principles of Application."

TERCENTENARY OF THE ROYAL SOCIETY

FOR all the rapid change that continuously dissolves and recreates the scene of human activity the men who originated the Royal Society and who are in a sense the fathers of the present age are no further removed from us than our nearer ancestors. This was the theme with which SIR CYRIL HINSHELWOOD, O.M., P.R.S., opened his address at the Tercentenary Celebrations of the Royal Society. In a wide ranging discourse, the President went on to point out that the full fruition of scientific work depends upon three things, the desire to know, the initiative to find out and the awareness to apply. Highly special conditions have to be fulfilled before the plant will bloom, before the flower will fruit and before the fruit will ripen. Furthermore scientific investigation needs material ways and means, and the further knowledge advances the more lavish becomes the scale. The individual in isolation becomes, except under rare conditions, correspondingly impotent. What therefore must be created to mediate between the individual and the major group, is a specialised minor community large enough to command prestige and confidence, but with membership confined to those who place the claims of knowledge first. The principles which should govern the constitution of such a body are highly important. In SIR CYRIL'S view, an academy was therefore the natural body to provide for several vital things; non-commercial periodicals for the publication of discoveries, a measure of financial support for ideas still too embryonic to be of immediately obvious practical application, the mutual stimulus of association and discussion and the immaterial reward of honour for intellectual achievement. Governments may act as patrons. They can and do solicit and receive the help of learned men, they favour and encourage enterprises which they judge to be timely, but they cannot provide for men of science the intangible yet powerful encouragement which comes from acceptance and election by their peers. The academy, if it maintains high standards of unquestioned impartiality, sets the tone throughout the scientific community, and its influence is felt in every quarter.

This commemoration was a great event in the history of the Society. It was their duty not to predict, not to legislate, but to maintain within the larger community the smaller one in which creative activity can flourish. Its members owed a multiplicity of loyalties, none of which could be fulfilled without the others: to mankind in general, to their native land and to the Royal Society itself. But there were communities in time as well as space. The most original minds, in some sense isolated in all contemporary groupings, found their true affinities in continuing the sequence of their predecessors, and their fulfilment only in their successors. In a measure this was true not only of genius but of all men. It was what moved us in history, concluded SIR CYRIL. It was what the honouring of this occasion meant.

PROFESSIONAL APPOINTMENTS

3 lines 7s. 6d. (minimum), additional word 6d.—Box number 2s. extra.

For Box Numbers reply to BRITISH CHEMICAL ENGINEERING, Drury House, Russell Street, Drury Lane, London, W.C.2.

Technical Sales Engineer age about 25 years required by Chemical Engineering firm for position in London offering excellent prospects. Qualifications required are training to B.Sc., or equivalent and good knowledge of physics and heat transfer. Grounding in chemistry advantageous. Send full particulars including salary required to Box No. BCE 87.

TECHNICAL MANAGER

A well-established and rapidly expanding company engaged in the supply of solid/liquid separation equipment to the chemical and process industries requires a physical chemist or chemical engineer to fill the post of Technical Manager. This post will include responsibility for process applications, laboratory and pilot plant and will also include scope for process engineering development work. The man required should have a good degree and should be able to combine both a theoretical and practical approach to the work. An enthusiastic personality is essential since the post will involve high level contact with customers. The post will be at the Company's headquarters in the home counties, salary based on experience with a minimum of £1,400 p.a. Previous experience in separational work desirable but not essential. Applications in strict confidence should be addressed to the Technical Director, Box BCE 89.

NORTHERN ALUMINIUM CO. LTD., BANBURY

Require a CHEMICAL ENGINEER aged 26/32 to undertake design and development work in the Process Industries Section of the Sales Development Division. The post, which involves a variety of interesting projects, calls for technical competence and initiative, and candidates, preferably should have some knowledge of design in, and fabrication of aluminium. A good chemical engineering background and suitable academic qualifications to degree standard essential.

Write giving full details of education, experience etc. to:—

PERSONNEL OFFICER, NORTHERN ALUMINIUM CO., LTD., BUSH HOUSE, ALDWYCH, LONDON, W.C.2.

PETROCARBON DEVELOPMENTS LIMITED

have a number of vacancies for

SENIOR AND JUNIOR CHEMICAL ENGINEERS

to work on major projects in the

LOW TEMPERATURE AND PETROLEUM CHEMICALS FIELDS

The activities of the company cover all aspects of process design, plant testing and commissioning, and for the senior appointments a high degree of personal responsibility will be involved.

The company is small enough to give scope for individual achievement but its development policy and present activities are sufficiently extensive to provide a continuously interesting and diverse programme of work.

Applicants should possess a university degree in Chemical Engineering or equivalent qualification, and for the senior appointments, have had several years' design experience; a knowledge of the mechanical engineering problems involved in plant construction would be an added advantage.

Salaries will be generous and in accordance with academic qualifications and experience. Assistance will be given with house purchase and a car allowance will be payable for the senior appointments. A generous non-contributory staff assurance and pension scheme is in operation.

Apply to the Technical Director
PETROCARBON DEVELOPMENTS LIMITED
Sunlight House, Quay Street, Manchester 3.

THE INTERNATIONAL SYNTHETIC RUBBER COMPANY LIMITED

Britain's only large scale producers of Synthetic Rubber is seeking capable men of high calibre whose experience, qualifications and enthusiasm can match the challenging situation in a young and virile industry. Applications are invited for the position of:

PLANT DEVELOPMENT GROUP MANAGER

A senior Chemical Engineer is required to form and manage a small group of Engineers, to be engaged on plant development.

The duties of the Group will be mainly to:—

(a) Study existing equipment performance, carrying out plant trials where necessary, and design modifications for improved performance.

(b) Investigate and evaluate alternative machinery with a view to replacement of existing equipment where redesign is not satisfactory, or in preparation for future expansion projects.

(c) Take an active part in process design work on future expansion projects, and progress construction from there onwards to commissioning.

The Group will co-ordinate drafting, procurement, construction and commissioning, and will have direct contact with suppliers and contractors.

The Group Manager should be a qualified Chemical or Mechanical Engineer with several years of varied experience in Chemical Process Industries.

The Company operates generous Pension and Sickness Benefit Schemes and excellent working conditions exist in a modern plant situated close to the edge of the New Forest.

Salaries will be in line with the applicants experience and qualifications.

Written application stating age, qualifications, experience, and commencing salary expected should be addressed to the Personnel Manager of the Company at Hythe, Nr. Southampton.

A PROCESS ENGINEER

is required by a well known food processing company situated West of London.

The Company occupies a leading place in the application of the latest techniques to the processing of foods, and it is the Company's policy to increase this lead by a very active research and development programme.

The appointment will be in the process development and design section, and it carries an unusual degree of freedom in the development of original ideas through pilot plant and process design stages to the commissioning of full scale plant. A wide range of unit operations is encountered, and there is a strong emphasis on automatic control throughout the factory. The materials handled have interesting rheological and other properties.

The Process Engineer will be required to work in close co-operation with other members of management, and should therefore have several years' industrial experience, not necessarily connected with food processing.

Applicants, who should be between 25 and 40 years of age, must have a good Honours Degree in Chemical Engineering or equivalent qualifications.

The successful candidate will receive a commencing salary of £2.050 per annum, plus generous non-contributory benefits covering pension, life assurance and sickness.

Please write in confidence to the Personnel Manager, Box BCE 88.

Pfizer

Qualified

Chemical Engineer

Due to reorganisation a vacancy has occurred for a qualified Chemical Engineer to join the production team of Kemball, Bishop & Co. Ltd., which is the Chemicals Division of the Pfizer Group of Companies.

The position, which offers scope for initiative, will be based in London but also offers prospects within the Group.

The Group offers a good commencing salary with generous Non-contributory Pension and Life Assurance Schemes.

Applicants aged at least 25 years, with a minimum of two years production experience, are invited to write giving full particulars to:

The Personnel Manager,
KEMBALL, BISHOP & CO. LTD.
Crown Chemical Works, Three Mill Lane,
Bromley-by-Bow, London, E.3.

THE PFIZER GROUP

REPRESENTATIVES

WANTED, Representative for correspondence abroad, high earnings, instructions in writing. Write Fortuna Publishing Co., Vienna 1/8, Postfach 49.

EDUCATIONAL

MIDDLESEX COUNTY COUNCIL
Education Committee
BRUNEL COLLEGE OF TECHNOLOGY
Woodlands Avenue, Acton, W.3.
Department of Physics.
Head of Department:
Dr. C. A. Hogarth, F.Inst.P.

ADVANCES IN NON-DESTRUCTIVE TESTING

An evening course of ten lectures given by well-known specialists will be held on Wednesdays from 7 p.m. to 8.30 p.m., commencing 28th September, 1960. Fee is £1.

Further details from the College.

BRADFORD INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CHEMICAL TECHNOLOGY

The following full-time courses in CHEMICAL ENGINEERING will commence next September/October:—

(a) Four Year Sandwich Course leading to Diploma in Technology.

(b) Three Year Full-time Degree course for the B.Sc. (Chem.Eng.) External London University Degree, (also Institute Associateship).

(c) One Year Post Graduate Course for students with suitable exempting qualifications in Chemistry, leading to Graduate Membership of the Institution of Chemical Engineers.

Further particulars of any of the above may be obtained from the Registrar, Bradford Institute of Technology, Bradford 7.

TUITION

A.M.I.CHEM.E. More than one-third of the successful candidates since 1944 have been trained by T.I.G.B. All seeking quick promotion in the Chemical and Allied Industries should send for the T.I.G.B. Prospectus. 100 pages of expert advice, details of Guaranteed Home Study Courses for A.M.I.Chem.E., B.Sc.Eng., A.M.I.Mech.E., A.M.I.Prod.E., C. and G., etc., a wide range of Diploma Courses in most branches of Engineering. Send for your copy today—FREE T.I.G.B. (Dept. 43), 29 Wright's Lane, London, W.8.

SERVICE

SHOTBLASTING, METAL SPRAYING, COATING. Epikote, Araldite, P.T.F.E., P.T.F.C.E., Polythene, P.V.C., Neoprene and Hypalon coatings applied on SITE or at WORKS. LOYNE LIMITED, Margaret Street, Ashton-under-Lyne, Lancs. Tel. No. ASH 4551/2/3.

SELL US YOUR SURPLUS STAINLESS STEEL

SHEETS · PLATES · BARS · TUBES
SECTIONS · STRIPS · BLANKS · OFFCUTS

- **top prices paid**
- **offers by return or our buyer will call**
- **prompt collection and payment**

STAINLESS RECOVERIES LTD
Dover Road · Trading Estate · Slough · Bucks
Telephone: Slough 24622

British Chemical Engineering
A HEYWOOD PUBLICATION

Birthday at Warren Spring

THE Warren Spring Research Laboratory was opened just over a year ago by Viscount Hailsham, Q.C., then Lord President of the Council. To mark its birthday the laboratory has held its first open days—suffering the major interruption inseparable from such events, but presumably gaining by the increased understanding of its work among its visitors. This birthday is a good occasion to look back on the progress and achievements of its first year of existence.

It is now widely known that the laboratory is based on two new concepts for the Department of Scientific and Industrial Research. Planned as a versatile station, tied to no specified subject or industry, the Warren Spring Laboratory is able to carry out process research over a wide field and has facilities for pilot-scale investigations which cannot easily be carried out elsewhere. Furthermore, from the outset it has been planned in such a way as to place stress on carrying out sponsored research (which may or may not be published) as well as freely published basic work. In practice, the emphasis has been on chemical engineering and process development, including mineral processing, the latter being treated as a separate division. Within these fields, the unsponsored work appears to be so planned as to be of extensive service. For instance, the mass-transfer studies on gas-liquid systems are directed to providing basic data for distillation and gas absorption. Rather than studying a specific process, the aim is to find the influence in more general terms on plate mass-transfer efficiency of the gas-liquid interfacial area, the mass-transfer coefficient in the foam and the residence time distribution of the liquids passing across the plate. We have referred to these programmes both in an earlier account of the laboratory (May 1960, p. 351) and in our report on the International Distillation Symposium. Within the last few weeks a column of 12 perforated plates has been added to the facilities available; its response to alterations in a number of operating variables will be measured in order to find the relevant empirical equations and link the column to a computer. It must represent a severe loss to the laboratory that Dr. P. H. Calderbank, who has directed this central group of studies and last year received the Senior Moulton Medal of the Institution of Chemical Engineers, is due to move to Edinburgh University, where he has been appointed Professor of Chemical Technology.

Process development is in practice built around the Fischer-Tropsch work. Results from the main process research and economic appraisals will evidently have formed an important part of the material considered by the Wilson Committee on coal chemicals. It is unfortunate that we are unable to deal here with this subject, because we understand that the Committee report is likely to be published after we have gone to press. But in this division, too, there is a lively programme of basic research—in this case on catalysis. In his report for 1959* Mr. S. H. Clarke, the Director, has referred to the results of his inquiries made through the Association of British Chemical Manufacturers which suggested that industry would value more work in this field. The programme has, in fact, developed after extensive consultation and with the further asset of sponsorship by the National Research Development Corporation.

The Mineral Processing Division has been built on a nucleus of members of the former Fuel Research Station and others from the Mineral Processing Section of A.E.R.E., Harwell. While the laboratory as a whole has about 20% of its effort on a repayment basis, the figure for this division is about 75%. An Overseas Mineral Processing Advisory Committee has been set up to advise on priorities of projects requested by overseas territories. More effort is likely to be devoted to this field of work. In this division there is great interest in the possibilities of fully automatic control—perhaps along the lines we have noted earlier (July 1960, p. 461). Here the object will be to develop an overall system including the use of an optimiser but starting from control of the grinding. An important feature is the design of a sensing element for size range since no satisfactory device of this kind exists and it has been a weakness in earlier attempts to design such systems.

For completeness it should perhaps be noted that the number of non-industrial staff rose from 178 at the official opening to 226 at the beginning of the current year and has stayed at roughly this level. The complement is 249.

Reviewing this impressive set of projects, it is clear that great efforts have been made to sound industry and to ensure that the laboratory would be designed to meet its needs. This is not the central chemical engineering research organisation recommended by the Cremer Report in 1951. It is both more and less than that propect; more because it is intended to cope with any research problem, and less because under its terms of reference it need not continue to devote a high proportion of its effort to chemical engineering.

Both in the steps taken during planning and in the final programmes adopted, the laboratory has proved to be a fine example of collaboration and fruitful interaction between private and public enterprise. Long may it prosper.

* Report of the Warren Spring Laboratory, 1959. H.M.S.O., 1960, 3s.

621-52 : 66.067.5 : 621.928.3

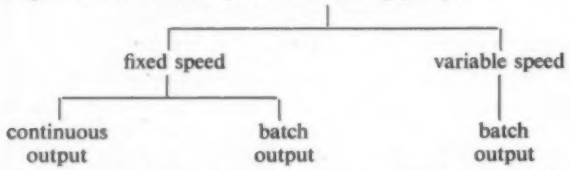
AUTOMATIC CONTROL OF CENTRIFUGALS

A survey of the methods of controlling batch type centrifugals

by F. BROADBENT, F.R.S.A., B.Sc., M.I.Chem.E., and
G. L. GRIMWOOD, B.Sc.(Eng)., A.M.I.E.E., A.M.I.Mech.E.

Introduction

For the purpose of considering automatic controls, centrifugals can be divided up in the following groups:



The fixed speed, continuous output centrifugal has a uniform flow of feed slurry to the machine and uniform flows of solids and liquids from the respective outlets. These machines have considerable but restricted applications and the control schemes are relatively simple. It is therefore proposed to limit these notes to the batch types which, generally speaking, are used where the standard of separation or washing required is higher than that possible with the continuous type.

A normal cycle of operations of a batch centrifugal is made up of a combination of the following processes:

(1) feed;
(2) spin;
(3) wash;
(4) classification of liquor centrifuged;
(5) spin;
(6) discharge;
(7) screen rinse.

Individual machines may require additional wash processes or the control of other associated operations of the chemical plant just preceding and following the centrifugal separation. For the most usual cases all these operations are carried out at the top speed of the machine, but, again, individual machines may require a variation in the centrifugal speed for certain of the processes that form part of the complete cycle.

The two basic methods of controlling the individual processes are those of sequence control and time control and most of the processes fall naturally into one or the other of these groups. The control of slurry feed to the centrifugal requires special consideration, as will be seen later.

Sequence Control

Operations that call for the completion of a mechanical movement, the flow of a pre-set volume of liquid from the tank or some similar measure are obviously best dealt with by sequence control. Examples of these applied to centrifugal operation are:

(1) *Discharge*

The discharge of solids at the end of spinning is made by a plough blade which travels through the centrifuged solids to discharge them down the chute. This blade makes one stroke through the solids and then returns to its original position. Some combination of limit switches and hydraulic actuation can be made to control this movement.

(2) *Washing*

Where a precise amount of wash liquor is required this can flow from a storage tank, the quantity required being controlled by tank level measuring devices.

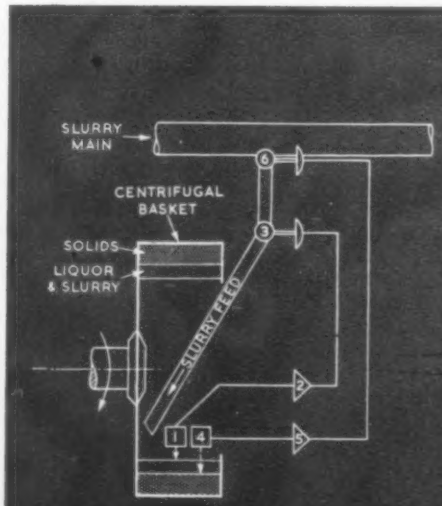


Fig. 1.
1. Measurement of liquor level.
2. Amplifier.
3. Rate control valve.
4. Measurement of solids level.
5. Amplifier.
6. On-off valve.

(3) *Spinning Time*

The spinning of a centrifugal should end when the flow-rate of the centrifuged liquor has fallen to a predetermined value. A device to give this sequence control offers worthwhile advantages when the filtration rate or slurry consistency varies. In many cases, however, spinning is fixed on a time basis which gives a simple and satisfactory means of control.

Sequence control is closely associated with the mechanics of the centrifugal and to be successful demands substantial consideration in the design stage of the machine. The degree to which this is so is not always apparent until an attempt is made to fit sequence controls to an existing centrifugal as additional automatic gear.

Timing Controls

Operations that are not naturally sequence controlled are usually controlled on a time basis. Quite often the control of wash liquor is carried out by timing the period at which a valve is opened and relying upon the known rate of flow to give the required liquor volume.

Whilst sequence controls are part of the centrifugal, timing controls are a separate item drawn from the increasingly wide variety of equipment available from the light engineering and electronic industries. The most popular type of process timer is synchronous motor driven and gives accurate timing for periods from a minute up to several hours or longer. Its main rival, the electronic timer of the capacity/discharge resistance type, is better suited for measuring times shorter than those normally required for centrifugal work. One of the most usual motor-driven timers is that containing a single synchronous motor driving a drum fitted with several cams, each of which operates a switch. The process required is set up on the cams to a time base and these control the processes. This timer has the advantages of simplicity and of operating both electric and pneumatic switches, but the disadvantage of being unable to control short time periods with sufficient accuracy when the time scale is long. This difficulty is overcome by using, in conjunction with such a timer, additional single cam timers of short scale length or electronic timers which are put into operation by the main drum timer as and when required.

Taken to the extreme, a chain of single cam timers, each controlling one part of the cycle of operations and with each cam driven by a separate synchronous motor, can be applied to the control of a centrifugal. This gives complete elasticity in adjustment but a substantial and often unnecessary increase in the complexity of the equipment if the number of processes controlled exceed two or three. A disadvantage is that the adjustment of individual process timers alters the overall cycle time unless sequence control of spinning is used.

Control of Feed

It is in the automatic control of the slurry feed to the centrifugal that the most interesting problems can arise. If the slurry feed can be controlled automatically then it is probable that the centrifugal can be made a completely automatic batch machine to re-cycle continuously. Whilst on the freely filtering slurries a simple sequence control for feed may be possible, many of the slurries used in the chemical industry are not of this type. Where the slurry is not freely filtering and it is possible that free liquor is present on the face of the solids during the feeding operation, then for the most effective control of the machine it is necessary to distinguish between the liquor and solids level.

The problems associated with slurry feeding under non-freely-filtering conditions are summarised as:

(1) The differentiation between liquor and solids levels in the basket.
(2) The control of feed rate.
(3) The control of feed end-point.
(4) The maintenance of a consistent feed slurry—or operation with varying slurry consistency.
(5) Avoiding restrictions and the build-up of solids in the slurry flow to the machine.

There is no general solution to these problems and each application must be taken on its merits. Usually some experimental work is necessary before the best solution can be found, and on occasions the problem proves insoluble. The various methods being used or developed for automatic feed control are:

(1) The control of feed volume by the level drop in the feed tank or through an integrating meter.
(2) The measure of the rate of filtration of the liquor leaving the centrifugal, again by means of a measuring tank or integrating meter.
(3) The measure of the position of the liquor face in the rotating basket by means of a mechanical device touching the liquor surface.
(4) The measure of the liquor position by means of a capacity probe.
(5) The measure of the solids position under the liquid, again by means of a capacity probe.

For the maximum utilisation of the centrifugal during feeding it is usually, but not always, desirable that the free liquor head within the basket is as great as possible and this

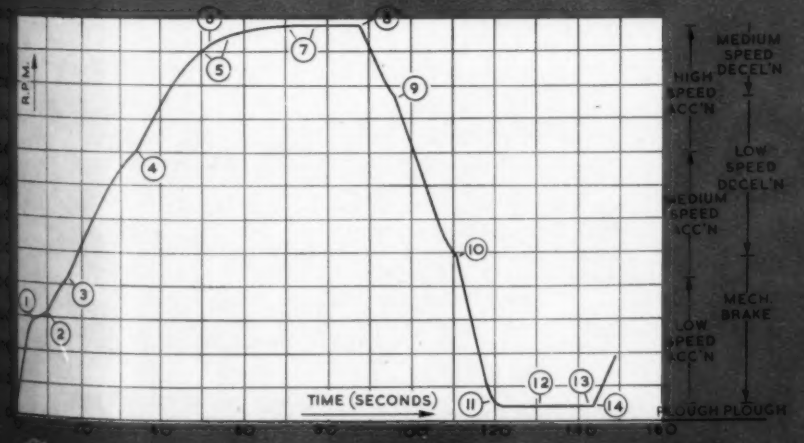


Fig. 2. A typical cycle of operations for a sugar centrifugal.

1. *Feed valve opens at predetermined speed.*
2. *Feed valve closes, by load indicator in basket, after 1100-1300 lb. of massecuite have been fed. Over-riding time interlock provided.*
3. *Acceleration transferred from low to medium speed winding; centrifugal accelerates to spinning speed and timing of spinning commences.*
4. *Acceleration transferred from medium to high speed windings.*
5. *First wash valve open. Duration of opening timed accurately by separate cam type timer.*
6. *Classification valve on centrifugal liquor outlet operated.*
7. *Second wash valve open.*
8. *Spin complete. Drive motor switched by time from high to medium speed for braking.*
9. *Regenerative braking transferred from medium speed to low speed by time or tachogenerator control.*
10. *Drive motor de-energised, mechanical braking introduced.*
11. *Mechanical brake lifted by tachogenerator control and low frequency power switched to motor.*
12. *Discharging under sequence control, 600-700 lb. of crystals ploughed out.*
13. *Classification valve returned to initial position.*
14. *Discharge complete, cycle repeats automatically.*

means controlling the liquor level as near the basket lip as is practical. The control of feed rate is then required with the passage of slurry through a partly closed valve, and the possibility of the build-up of solids at the valve. If a serious build-up of solids occurs it is necessary to forgo the maximum utilisation of the centrifugal and feed the machine in pulses through a valve that is either fully open or fully closed, the rate of flow being controlled by the on/off time ratio of the valve. The control problems presented by both these methods can be considerable and may need closed loop systems. A typical system of feed rate control is shown in Fig. 1.

Control of Speed

For certain products the problem of obtaining a balanced load can be solved by reducing the speed of the centrifugal for the feeding operation. Again damage to the centrifuged solids is much less if these are discharged at a low basket speed, and in some applications crystal damage must be a minimum. Thus on some machines it is necessary to control the speed of rotation of the centrifugal basket to obtain different speeds for the various processes.

The multi-speed induction motor, when designed for a high inertia drive, is a particularly suitable drive unit for centrifugals if the synchronous speeds available are suitable for the duty. This type of motor has no brush gear or rotating insulated windings, it is of robust construction and can be made enclosed pipe ventilated, flameproof, etc., without great difficulty. The speeds needed from this type of motor are obtained by closing the appropriate winding contactors, but steps must be taken to ensure that acceleration and deceleration between the various speeds are virtually complete before further switching takes place—otherwise the motor losses become excessive. Where the inertia of the basket load is comparatively small compared with the inertia of the basket itself (and this is particularly the case with centrifugals with the larger diameter baskets), then successful control of the induction motors can be carried out by using time control. An alternative to this is the use of a current relay, the coil of which carries a current proportional to the input current to the motor. As the motor input current is a function of the motor speed the current relay can be set to operate at a particular predetermined speed to switch the motor. The most accurate and precise method is to use a simple closed loop system with a permanent magnet tachogenerator on the motor shaft feeding back a voltage proportional to speed. This signal is then compared with a fixed voltage (which is preset to select the required speed) and the resultant difference signal used to operate the motor contactors.

The Centrifuging of Sugar

The biggest application for centrifugals is in the sugar industry where the annual world output is approximately 45 million tons. Practically all this material is centrifuged, some of it more than once, in batch treatment machines. In modern installations all processes except feed are controlled automatically and in an increasing number of installations the feed also is automatic.

The type of centrifugal generally adopted for sugar is the overdriven bottom-discharge machine. The output of such a centrifugal of the 48-in. size on white sugar is of the order of 5 to 10 tons of crystals per hour.

The special conditions when centrifuging a white sugar slurry (A massecuite) are:

(1) A reasonably low speed for feeding, otherwise uniform distribution to the load is not possible.

(2) A high rate of acceleration.

(3) The minimum amount of wash water and easy adjustment of the time of application.

(4) A very high purity of crystal product (of the order of 99%).

(5) A very low discharging speed to avoid crystal damage.

(6) The highest output rate from the centrifugal consistent with the above requirements and at the lowest capital cost.

(7) Low power consumption.

The control problem is one that demands some of the techniques discussed earlier. It is necessary to arrange for the process operations to be carried out at certain speeds and the control equipment must effect the speed changes as well as process operations. Sequence controls are necessary during feeding and discharging and time controls are used for the remaining processes. As with chemical type machines the most awkward part of the process to control automatically is that of feed, and in the development of the machine this has been the last of the processes to which successful controls have been applied.

Whilst the type of centrifugal used by the sugar industry is not generally the most suitable for the chemical industry, it will be seen that the problems of controlling both types of centrifugal are much the same. The substantial number of centrifugals used in the sugar industry has created a background of experience that is directly applicable to controlling other types of centrifugals and this has been applied to good effect.

A typical cycle of operations for a sugar machine is shown in Fig. 2, with relevant notes on the methods of carrying out the various process controls.

Safety and Interlocks

Process controls cannot be divorced from consideration of the interlocks necessary to ensure the safety for both operator and plant. As every plant engineer will know, interlocks can be added *ad nauseam* and the main problem is the inclusion of a realistic set of interlocks. It is difficult to generalise about the fitting of interlocks and they must be considered on the merits of each installation, the safety regulations, and the cost of not fitting them.

Generally speaking, the position regarding interlocked covers, moving parts and the safety of the operators is quite clear and has been the subject of articles by authors much better qualified than the writers. Decisions on the need of process interlocks are not always so easy to make. For example, the consequence of a wash valve sticking open at the wrong time can be expensive. However, whilst no apparatus can be installed to close the valve that will not close, interlocks can be provided to ensure that the cycle of operations does not proceed and a warning is given if the valve fails to close after it has been open for a predetermined time. Interlocks on the process usually follow this pattern.

Where sequence controls are fitted it is not unusual to provide a time control, set to a time somewhat longer than the normal sequence time, to act as an interlock and to effect over-riding control should the sequence not complete in the time preset. This is an interlock invariably found on automatic feed equipment where the equipment controlling the feed is complex.

When a centrifugal has not been fed with slurry correctly the "cake" of solids in the basket can be unsymmetrical. Similar conditions arise if a filter cloth breaks and allows a local passage for solids. Again if a centrifugal is brought to rest with the basket full of solids and started again, movement of the solids can produce the same result. When free liquor is present on the face of the solids or if the basket speed is low the unbalanced mechanical forces due to the lack of symmetry of the solids are usually slight. As the liquor is centrifuged off, or as the speed of the basket increases, these mechanical forces can become excessive.

An interlock to brake the centrifugal to a low speed or to rest under conditions of excessive out-of-balance forces is a useful addition to machines working difficult slurries or operating under fully automatic control. The interlock compares the vibrations on selected parts of the centrifugal and operates when the degree of vibration exceeds the tolerable level.

Site Hazards

Equipment in corrosive, explosive and dust hazard locations provide particular control problems. Here the tendency is to remove the more complex control apparatus from the centrifugal location to a point outside the danger area. This leads to an increase in the complexity of the equipment and a demand for more interlocking, first because the hazard is greater and, secondly, because a large proportion of the control equipment is removed from the machine and out of sight of the operator.

Layout of Equipment

In recent years considerable attention has been paid to the appearance and external design of industrial equipment. This has affected the appearance of both the centrifugal and the control equipment that goes with it. For the usual complex installation the essential control and indicating equipments are brought to a control desk for the easy and continuous display of the operation. To these can be added flow-rate meters and similar apparatus associated with other adjacent parts of the process, together with mimic diagrams and rapid fault-indicating gear. When the machines are fully automatic then some simplified presentation of the state of each centrifugal at any instant is essential for easy and accurate supervision of the plant. This presentation must be in an attractive, easily read and standardised form to keep the supervising time necessary to a minimum.

Conclusions

The application of well-tried methods provides the answer to most of the problems arising in the control of centrifugals. No simple method to control slurry feed has been found that is suitable for the increasing variety of materials to be separated. Generally, the advantages of controlling slurry feed are substantial as the centrifugal can then function as a fully automatic recycling machine and it becomes necessary to introduce the more advanced control methods. Considerable progress is being made with these methods, extending the possibility of automatic control to the more difficult slurries.

The rapid advance of control technology is also affecting centrifugal control. Static switching and logic methods offer improvements, the extent of which is still being examined, and plant optimisation may well demand centrifugals and control schemes in the future of very exacting performance.

ACKNOWLEDGMENTS

The authors wish to thank the board of directors of Thomas Broadbent & Sons Ltd. for permission to publish this paper.

Releasing Pressure in a Container to Atmosphere

Problems in gas dynamics are usually solved by assuming that changes occur adiabatically. In some cases heat transfer cannot be ignored and the alternative assumption is made that changes occur isothermally. When, as is often the case in practice, limited heat transfer occurs, the most usual approach is the semi-empirical one of assuming the gas to expand according to the law, $p\,V^n = \text{constant}$ and measuring n experimentally. More sophisticated treatments based on estimates of the actual heat transfer that occurs are generally too complicated to be useful.

A case of interest to chemical engineers where heat transfer needs to be considered is the discharge of compressed gas from a reservoir. The usual problem is to calculate the time taken to reduce the pressure by a given amount or to estimate the discharge that occurs in a given time. For rapid discharge, adiabatic conditions can be assumed[1, 2, 3, 4] and for fairly slow discharges the gas left in the reservoir can be assumed to remain at constant temperature.[5] Alternatively some intermediate law of expansion can be assumed.[6]

Type of Expansion Important

A fresh approach is made in a recent A.S.M.E. paper by Potter and Levy,[7] where they properly recognise that the essential thing to establish in the nature of the gas expansion is a vessel from which gas is escaping. They therefore made simultaneous records of temperature and pressure inside the container during discharge and found that, with their apparatus, near-adiabatic conditions obtained for the first 10 seconds or so of discharge, but thereafter heat transfer by convection played an increasingly important part in modifying the gas expansion.

Air or dry nitrogen was discharged from a cylindrical vessel of 2 cu. ft capacity, the interior surface of which was screened with aluminium foil to act as a radiation shield and reduce the effective thermal capacity of the walls. It was charged to some 4 atm. pressure and could be emptied through a quick opening valve in between 16-200 seconds, depending on the size of orifice fitted. Several thermocouples were placed along the axis of the cylinder, but no axial change in temperature was ever detected.

Occurrence of Heat Transfer

The temperature reduction was quoted as a fraction of that expected from isentropic expansion. This was always less than one, indicating that heat transfer was occurring. After each time interval the ratio was smaller when moist air was used, presumably because of the heat content of the water. A sharp change was observed in the temperature/time relationship after discharging for about 10 seconds. Calculations show that heat transfer by radiation could account for the initial departure from isentropic expansion, but in the later stages it is assumed that heat transfer by convection must be taking place to account for the increasing rate of approach to isothermal expansion. It is curious that the effect should occur as abruptly as their data indicates.

This paper has not solved once and for all the problem of calculating imperfect discharge from vessels under pressure, but Potter and Levy have undoubtedly shown the right way to approach this problem and have given some useful information on the part played by heat transfer. It is hoped that they will continue their researches and obtain more data under a wide variety of conditions.

This article was prepared by P. N. Rowe of the Chemical Engineering Division, Atomic Energy Research Establishment, Harwell, Berks.

REFERENCES

[1] Giffen, E. *Rapid Discharge of Gas from a Vessel into the Atmosphere*, *Engineering*, 1940. **150**, 134, 154 and 181.
[2] Benson, R. S. "Discharge of Gas from a Cylinder to Atmosphere", *The Engineer*, 1955, **199**, p. 546.
[3] Kestin, J., and Glass, J. S. "Rapid Discharge of Gases from Vessels", *Aircraft Engineering*, 1951, **23**, p. 300.
[4] Weaving, J. H. "Discharge of Exhaust Gases in Two-stroke Engines", *Proc. J. Mech. Eng.*, 1949, **161**, p. 98.
[5] Rowe, P. N. "Releasing Pressure in a Container to Atmosphere", *Brit. Chem. Eng.*, 1960, **5**, 4, p. 292.
[6] Geyer, E. W. "The Time Discharge of High Pressure Gases", *The Engineer*, 1939, **168**, p. 60.
[7] Potter, J. H., and Levy, M. J. "The Free Expansion of Dry and Moist Air", A.S.M.E. Prep. 60-SA-23, 1960.

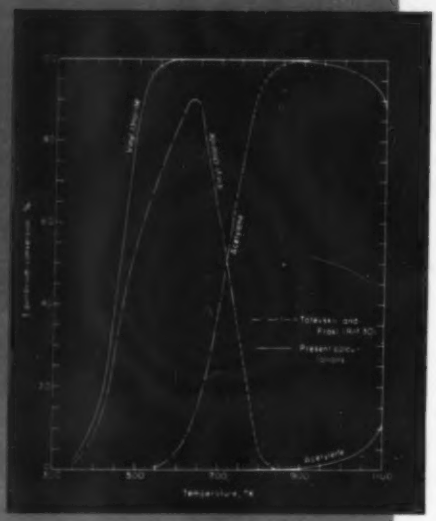


Fig. 1. Equilibrium conversion of ethylene dichloride to vinyl chloride and acetylene.

66.094.6: 661.723.622

THERMAL DEHYDROCHLORINATION OF ETHYLENE DICHLORIDE

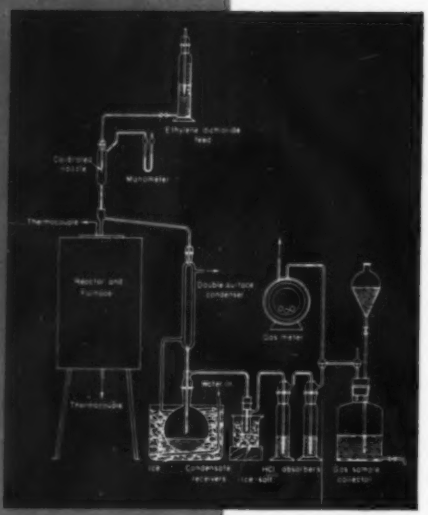


Fig. 2. Diagrammatic sketch of apparatus.

VINYL chloride is commercially produced either by the addition of hydrochloric acid to acetylene or by the elimination of the acid from ethylene dichloride. There are broadly two methods by which ethylene dichloride is dehydrochlorinated: liquid phase akali process which is seldom employed industrially, and direct vapour phase dehydrochlorination (thermal or catalytic) according to the reaction

$$CH_2ClCH_2Cl \rightleftharpoons CH_2CHCl + HCl \quad \ldots.(a)$$

In the present paper the literature on this reaction is briefly reviewed, thermodynamic considerations are discussed and results of experiments carried out to study the process kinetics of the thermal dehydrochlorination of ethylene dichloride are reported.

Literature Review

A large volume of data is available both on the catalytic and thermal dehydrochlorination of ethylene dichloride. The use of a variety of solid catalysts, e.g., active carbon, alumina, burnt clay, bauxite, activated silica gel, etc.,[5, 6, 8, 14, 15, 16, 19, 20, 23, 25, 26, 33] has been proposed. Of these, active carbons (directly or impregnated with chlorides of barium, copper, tin, etc.) appear to have been most widely investigated. Reports suggesting a long active life of these carbons are meagre.[6, 22] However, the observations of Doraiswamy and Pai[11] have shown that the life of these catalysts is very short, conversions falling from about 95 to 30% in less than 6 hr on an average; extension of this work to impregnated carbons has not yielded any encouraging results. The use of gaseous catalysts, mainly oxygen and chlorine, has also been investigated.[3, 4]

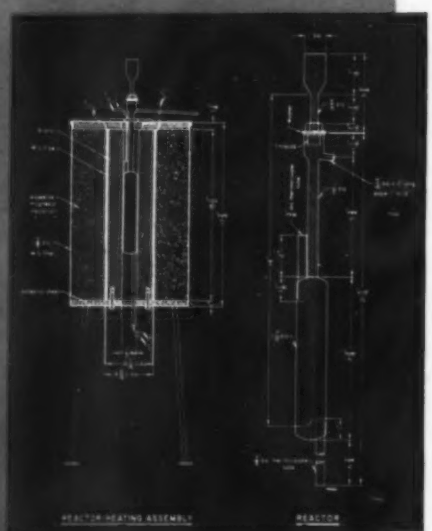


Fig. 3. Details of reactor heating assembly.

Reports on the thermal dehydrochlorination of ethylene dichloride are less extensive.[2, 3, 12, 14, 29, 31, 32, 33] The use of inert packing materials and of reactors of different diameters has also been explored,[3, 9, 10] but the data are too scanty to enable clear conclusions.

In the majority of investigations reported, detailed information on the effect of the two important process variables, space velocity and temperature, is lacking. A critical examination of all the available data, brought to a common denominator and summarised in tabular form (table not shown), has revealed that temperatures up to 650°C and pressures up to 8 atm have been employed, space velocities ranging from about 50 to 1400 reciprocal hours (calculated to conform with the definition given later).

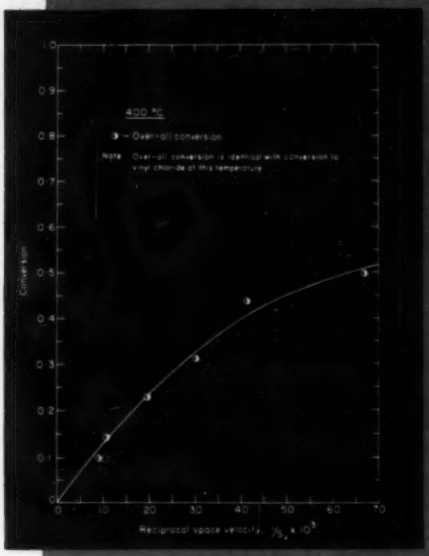


Fig. 4. Experimental conversion. $1/S_v$ plot at 400°C.

A study of the kinetics and thermodynamics of a reaction producing vinyl chloride

by L. K. DORAISWAMY, P. H. BRAHME, M. U. PAI and S. CHIDAMBARAM

A few studies on the kinetics of this reaction have also been reported.[2, 3, 7] Barton and collaborators[2, 3] carried out experiments using both static and dynamic systems and observed that, unless the ethylene dichloride used was of exceptional purity, results tended to be erratic and irreproducible. On the basis of the observed inhibiting action of small amounts of propylene, *n*-hexane and nitric oxide, a radical chain mechanism for this reaction was proposed and the experimental results fitted into a first-order rate equation up to half decomposition. This equation is not of much use in reactor design.

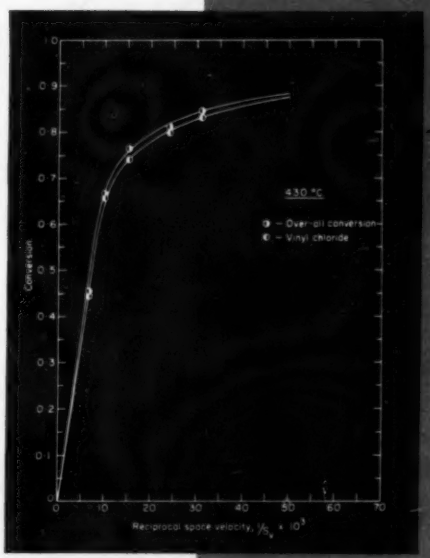


Fig. 5. Experimental conversion. $1/S_v$ plot at 430°C.

Thermodynamic Considerations

The significant reactions that occur in addition to the main reaction (a) when ethylene dichloride is heated at elevated temperatures are:

$$CH_2CHCl \rightleftharpoons C_2H_2 + HCl \quad \ldots . (b)$$

$$CH_2ClCH_2Cl \rightleftharpoons H_2 + 2HCl + 2C \quad \ldots . (c)$$

One of the main factors affecting the economics of vinyl chloride production is the extent to which the consecutive reaction giving acetylene, and the pyrolysis of ethylene dichloride, can be minimised.

The reported studies on the thermodynamics of this complex reaction show conflicting results. Barton and Howlett[3] obtained 100% conversion to vinyl chloride at 357°C and practically no acetylene up to 480°C in a static system. On the other hand, the equilibrium calculations of Tatevskii and Frost[20] show that, while there is complete conversion of ethylene dichloride at these temperatures, almost 55% of the vinyl chloride formed is further dehydrochlorinated to acetylene; their results are plotted in Fig. 3. In addition to these conflicting data, Ghosh and Guha[15] have presented a simple free energy relation for reaction (a), according to which it would be necessary to employ temperatures beyond 650°C to obtain almost complete conversion to vinyl chloride. This is clearly in contradiction to the results of Barton and Howlett as well as of Tatevskii and Frost.

It was thus necessary to recalculate the equilibrium constants and conversions for the two reactions; this has been done using the latest available data. The values of the heats and entropies of formation of all the constituents at 25°C were taken from the literature[18, 20] and confirmed by calculations based on group contributions. The values of the constants, *a*, *b*, *c*, *d*, of the specific heat equations were also available in the literature.[1, 18, 21] The final free energy rela-

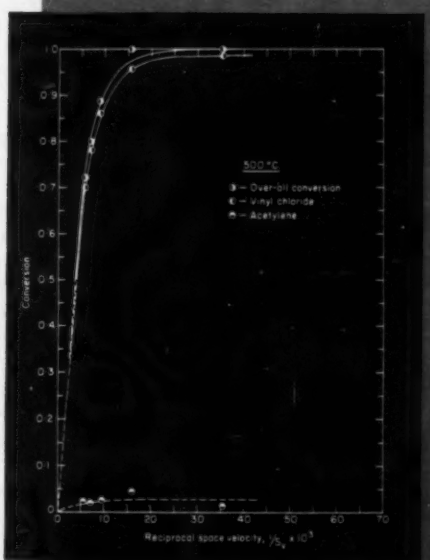


Fig. 6. Experimental conversion. $1/S_v$ plot at 500°C.

tions established for reactions (a) and (b) are:

$$\frac{\triangle G^\circ}{T} = R\ln K = \frac{17{,}308}{T} - 4.2201\ \ln T + 0.7318 \times 10^{-2}T$$
$$-0.2541 \times 10^{-5}T^2 + 0.04644 \times 10^{-8}T^3 - 7.7568 \ldots (1)$$

$$\frac{\triangle G^\circ}{T} = R\ln K = \frac{39{,}478}{T} - 6.714\ \ln T + 0.3442 \times 10^{-3}T$$
$$+ 0.0908 \times 10^{-5}T^2 - 0.3624 \times 10^{-9}T^3 + 11.6311 \ldots (2)$$

The equilibrium conversions calculated from Equations (1) and (2) are plotted in Fig. 1. It is evident that in the temperature range involved (300 to 600°C) reaction (a) is predominant with only traces of acetylene being formed beyond 500°C. The exothermic reaction (c) has a very high value of K in this range, but this is not significant, since the rates of pyrolysis are known to be quite low below about 500°C.

As the equilibrium conversions have been calculated on the basis of uncorroborated data for standard heats of formation, these values cannot be taken as final. However, they conform much more closely to experimental values of equilibrium conversions than the other reported calculations.

Symbols Used

A = constant of Arrhenius equation;
E = energy of activation, cals./g-mole;
F = feed rate, g-moles/hr;
$\triangle G^\circ$ = standard free energy change, cals./g-mole;
K = equilibrium constant;
k = first-order rate constant, litre/hr²;
R = gas constant, cals./g-mole;
r = reaction rate, g-moles/hr/22.40 litres of reactor volume;
s = selectivity of reaction for vinyl chloride;
S_v = space velocity, cc/hr/22.4 litres of reactor volume;
T = temperature, °K;
t = temperature, °C;
x = overall conversion of ethylene dichloride to various products, g-mole/g-mole feed;
x_1 = conversion of ethylene dichloride to vinyl chloride, g-mole/g-mole feed;
x_2 = conversion of ethylene dichloride to acetylene, g-mole/g-mole feed; and
x_3 = conversion by pyrolysis, g-mole/g-mole feed.

Experimental Work

Apparatus

A diagrammatic sketch of the apparatus used is shown in Fig. 2. Ethylene dichloride was fed into the reactor through a calibrated nozzle; various methods were tried for obtaining a constant rate of feed, but it was found that the simple principle of the Marionette bottle could be used with accuracy and was hence adopted in this investigation. The details of the reactor heating assembly and of the reactor are shown in Fig. 3. The reactor heating assembly consisted of a bronze thermostatic block $4\frac{7}{16}$ in. in diam. into which a $1\frac{1}{2}$-in.-diam. hole was drilled to accommodate the reactor. The block was surrounded by a mild steel pipe heated by electrical resistance wire; this enabled easy replacement of the heating element in case of failure. The reactor shown was the one finally selected after a few other designs were tried. This reactor had the following advantages: the feed could be preheated almost to the reaction temperature without an additional preheater; the total volume of the preheater and reactor outlet tubes in the heated zone was less than 7% of the actual reaction volume so that any reaction taking place in these tubes could be neglected, and space velocities based on an isothermal reaction zone could be accurately calculated. Great care was taken in the design of the reactor and heating assembly to maintain temperatures constant to within 2°C.

The products of reaction from the reactor were passed through an ice-cooled condenser where unreacted ethylene dichloride was removed, a trap cooled by ice-salt mixture for complete condensation of ethylene dichloride, then through an absorption train for HCl removal, and finally through a wet gas meter. Provision was made for withdrawing gas samples for analysis at regular intervals.

Procedure

No attempt was made to obtain ethylene dichloride of absolute purity as was done by Barton *et al.*, since the object of this investigation was to make applied kinetic studies using technical grade ethylene dichloride (boiling range: 82–84°C at 760 mm pressure).

Fig. 7. Experimental conversion. $1/S_v$ plot at 550°C.

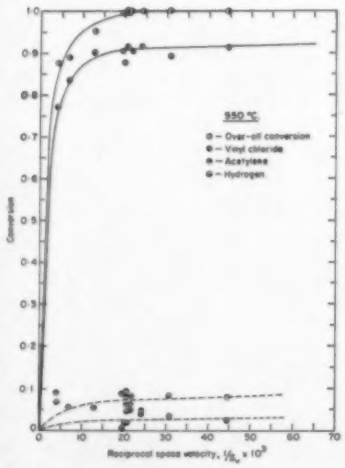


Fig. 8. Pseudo-first-order plots for low conversion range.

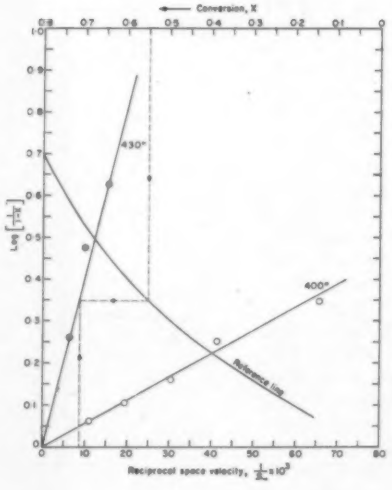


Fig. 9. Pseudo-first-order plots for high conversion range.

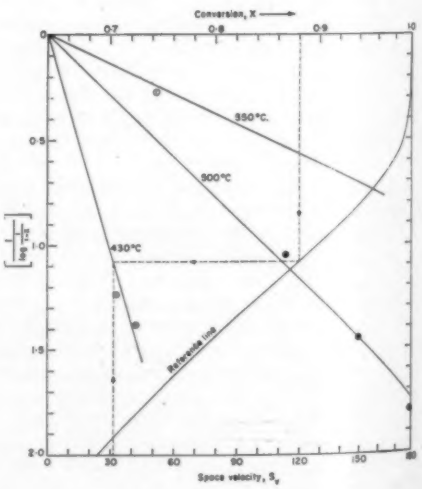


TABLE I—Experimental Results

Run No.	Temperature °C	Feed Rate g./hr	S_V litre/hr	$\frac{1}{S_V} \times 10^3$ hr	x	x_1	x_2	x_3
16	400	10.67	14.96	66.84	0.4980	0.4980	—	—
15	,,	16.95	24.19	41.33	0.4370	0.4370	—	—
13	,,	22.95	32.93	30.36	0.3100	0.3100	—	—
14	,,	35.38	50.93	19.63	0.2260	0.2260	—	—
12	,,	63.84	91.62	10.91	0.1410	0.1410	—	—
11	,,	76.83	110.43	9.05	0.0988	0.0988	—	—
8	430	22.60	32.48	30.78	0.8431	0.8337	0.009694	—
9	,,	29.09	41.75	23.95	0.8117	0.8026	0.006008	—
6	,,	45.81	65.63	15.23	0.7635	0.7404	0.003825	0.001441
10	,,	71.60	102.82	9.72	0.6649	0.6612	0.003827	—
7	,,	106.80	153.22	6.52	0.4528	0.4514	0.001290	—
2	500	19.657	28.22	35.44	1.00	0.9874	0.01159	0.00103
1	,,	44.6218	63.62	15.72	1.00	0.9595	0.03558	0.00488
3	,,	78.72	113.08	8.84	0.888	0.8616	0.02625	0.00087
4	,,	103.90	149.09	6.70	0.8009	0.7820	0.02169	—
5	,,	123.60	177.36	5.63	0.7230	0.7007	0.02249	—
26	550	15.64	22.47	44.50	1.00	0.9126	0.07131	0.01582
24	,,	22.56	32.57	30.89	1.00	0.8939	0.0258	0.0800
25	,,	28.99	41.19	24.28	1.00	0.9170	0.0450	0.0378
22	,,	33.16	47.49	21.06	1.00	0.9007	0.07764	0.02192
19	,,	33.70	48.38	20.66	0.9931	0.9145	0.06075	0.01778
18	,,	34.018	48.61	20.57	1.00	0.8786	0.0815	0.03981
20	,,	35.46	50.85	19.66	0.9960	0.9053	0.0859	0.00495
28	,,	54.01	77.50	12.90	0.9510	0.9022	0.0490	—
27	,,	102.10	146.50	6.83	0.8917	0.8373	0.05434	—
17	,,	170.60	244.14	4.096	0.877	0.7710	0.0861	0.0670

In making an actual run, the heat input to the reactor was adjusted to give the required temperature for the feed rate employed during the run. The feed rate was maintained constant (less than 2% error) at the desired value by controlling the number of drops falling through a calibrated nozzle. The actual amount of ethylene dichloride fed was determined both by weighing the feed bottle before and after a run of known duration and from the values of feed rate and time of run. Gas samples were collected at regular intervals in order to get a representative sample over the entire run.

Product Analysis

The products from the reactor were analysed for hydrogen chloride, ethylene dichloride, vinyl chloride, acetylene and hydrogen. While the determination of hydrogen chloride and ethylene dichloride was straightforward, the estimation of the other constituents had to be carefully worked out.

Vinyl Chloride

It was observed that a sizeable portion of vinyl chloride formed during the reaction was dissolved in the condensed, unreacted ethylene dichloride. The error introduced by neglecting this was high, particularly at low ethylene dichloride conversions—i.e., at high feed rates and low reaction temperatures. The vinyl chloride dissolved in ethylene dichloride was estimated by the bromide–bromate method using potassium iodide and titrating the liberated iodine against standard sodium thiosulphate. The vinyl chloride in the gas sample was estimated by determining the total unsaturateds in an Orsat apparatus and by subtracting from it the amount of acetylene determined by the method given below. Thus the *total* vinyl chloride was known.

Acetylene

Of the different methods tried for estimating acetylene in the presence of vinyl chloride, the method proposed by Siggia,[27] involving the use of alcoholic silver nitrate in a special apparatus, was finally chosen. The accuracy of this procedure was tested by estimating acetylene in acetylene-vinyl chloride mixtures of different known compositions and was found to be dependable even for mixtures containing less than 5% acetylene, the normal region of interest in this investigation.

Hydrogen

This was determined by the difference between the total gas and unsaturateds.

Results

Experiments were carried out in the temperature range 400–600°C and at space velocities from about 15–250 hr^{-1}. The results of all the runs are summarised in Table I. Runs made at 600°C were not considered reliable, as it was not possible to maintain constancy of temperature during a run even at very low space velocities.

Throughout this study reaction rates are expressed as g. moles/hr/22.4 litres of reactor volume to conform with the conventional definition of space velocity

$$S_v = \frac{F}{V_r} \qquad \ldots . (3)$$

where F is the feed rate in lb. moles or g. moles/hr and V_r is the reactor volume in 359 cu. ft or 22.4 litres. Experimental conversions for all the four temperatures employed are plotted against reciprocal space velocity ($1/S_v$) in Figs. 4 through 7. It is clear that acetylene formation and pyrolysis are almost absent at temperatures up to about 430°C and, as predicted by earlier thermodynamic calculations, reaction (a) yielding vinyl chloride is predominant over the entire range of temperatures and space velocities investigated. The equilibrium plots of Fig. 3 indicate that no acetylene can be formed at temperatures up to about 600°C, but the experimental results at 550°C show that about 5% of the feed is converted to acetylene. These small deviations are to be expected in the absence of precise experimental values of the heats of reaction.

Kinetic Analysis of Data

In a complex reaction of this type, involving both simultaneous and consecutive reactions, a complete kinetic analysis of the data is difficult. The most useful approach is that of Hougen,[17] which involves material balance between the individual rates of the different reactions on the one hand and the experimentally determined overall rates of formation (or disappearance) of the different constituents on the other. In cases where the mole fractions of some of the products are small, the errors in rate determination (by graphical differentiation) tend to be particularly large so that the accurate computation of the individual rates becomes difficult. In the present complex reaction, not only

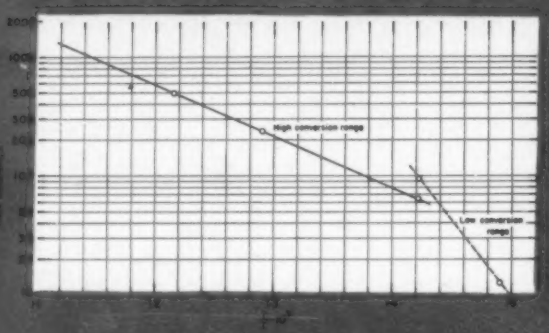


Fig. 10. Temperature dependence of rate constants.

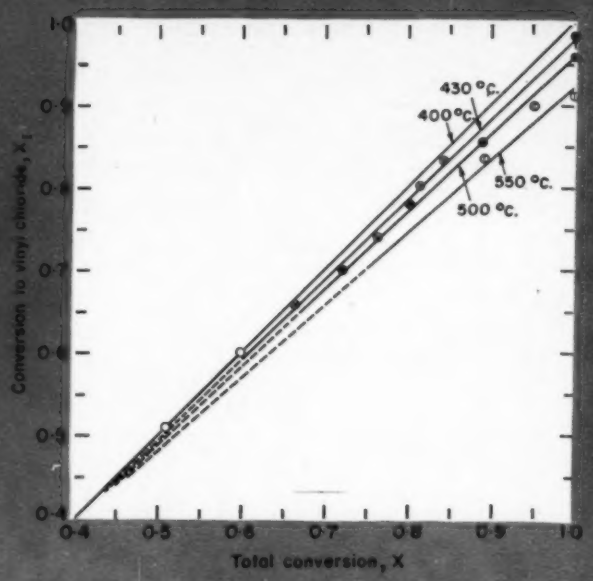


Fig. 11. Conversion to vinyl chloride as a function of total conversion.

are the mole fractions of acetylene and hydrogen small but there is a slight scatter of experimental points for these products (as is common in most kinetic studies); application of this method therefore did not lead to any satisfactory rate equations.

An examination of Figs. 4–7 reveals that there is a change in the average slope of each of the curves, particularly noticeable at 430°C, beyond a certain conversion. A single correlation over the entire conversion range is therefore not possible. The best method of correlating such rate data is to assume pseudo-first-order kinetics and develop separate rate equations for the two ranges of conversion.

Overall Reaction Rate

Let the overall conversion of ethylene dichloride to various products be x. Then, assuming a first-order reaction,

$$r = k(1 - x) \qquad \ldots . (4)$$

Substituting this equation in the flow-rate equation,

$$\frac{1}{S_v} = \int_0^x \frac{1}{r}\,dx \qquad \ldots . (5)$$

and integrating, one obtains,

$$\log\left(\frac{1}{1-x}\right) = \frac{k}{2.303}\left(\frac{1}{S_v}\right) \qquad \ldots . (6)$$

Equation (6) is best used for the low conversion-high space velocity region, since a plot of $\log\left(\frac{1}{1-x}\right)$ vs. $1/S_v$ must yield a straight line which extrapolates to $1/S_v = 0$, thus rigidly fixing one of the points on the line. For the high conversion-low space velocity region, on the other hand, it is necessary to re-write Equation (6) in the form

$$\frac{1}{\log\left(\frac{1}{1-x}\right)} = \frac{2.303}{K} S_v \qquad \ldots . (7)$$

Thus a plot of $1/\log\left(\frac{1}{1-x}\right)$ vs. S_v now gives a straight line which must extrapolate to $S_v = 0$.

An inspection of Figs. 5–7 shows that almost complete conversion is achieved at fairly low values of $1/S_v$ and the change in slope mentioned earlier takes place within this high space velocity region. As the maintenance of a constant temperature (to within 2°C) at these high space velocities was difficult, each run had to be repeated several times before it could be considered reproducible. Consequently, a large number of experimental points were not obtained in the high space velocity region, particularly at the higher temperatures. For plotting such kinetic data an excellent method has been suggested by Hougen and Watson.[18] Plots based on their method for both low and high conversion regions are presented in Figs. 8 and 9 respectively. The curved lines are reference lines connecting x and $\log\left(\frac{1}{1-x}\right)$ or $\frac{1}{1/\log\left(\frac{1}{1-x}\right)}$ and, for any single reliable run, the point may be plotted by drawing a vertical line from the given value of x down to the reference line and then moving horizontally till the corresponding space velocity is reached, as indicated by dotted lines in the figures. When the data for all the temperatures were plotted in this manner, a distinct change in the first-order rate was noticed at 430°C at a conversion of about 80%, thus confirming the view that the rate equations should be based on two regions of conversion.

It was found that the low conversion plots for all the temperatures correlated the data well up to about 80% conversion, while the high conversion plots correlated the data in the range 80–100%. The scatter of points was largest for the runs at 550°C. Fig. 8 does not include any results for 500 and 550°C, since low conversion data at these high temperatures were not obtainable without sacrifice of accuracy.

Specific rate constants were calculated for all the temperatures by measuring the slopes of the lines. An Arrhenius plot of the rate constants for the high conversion range yielded an excellent straight line, as shown in Fig. 10. As data for only two temperatures are available in the low conversion range, one cannot be certain of the applicability of the Arrhenius plot in this region; nevertheless, a correlation is developed on the results of these two temperatures and it is believed that this relationship is also valid in view of the general reproducibility of the results. Thus, for both the regions, the temperature dependence of the rate constants is expressed by:

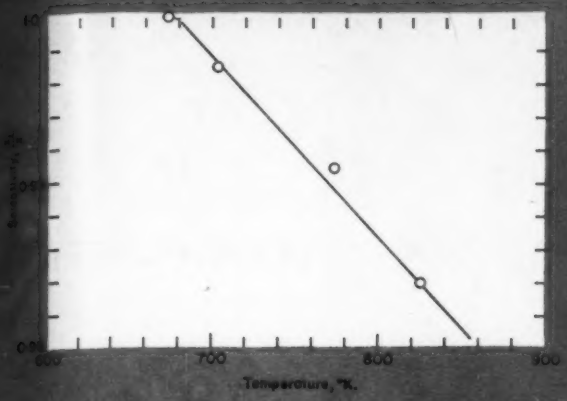


Fig. 12. Average selectivity as a function of temperature.

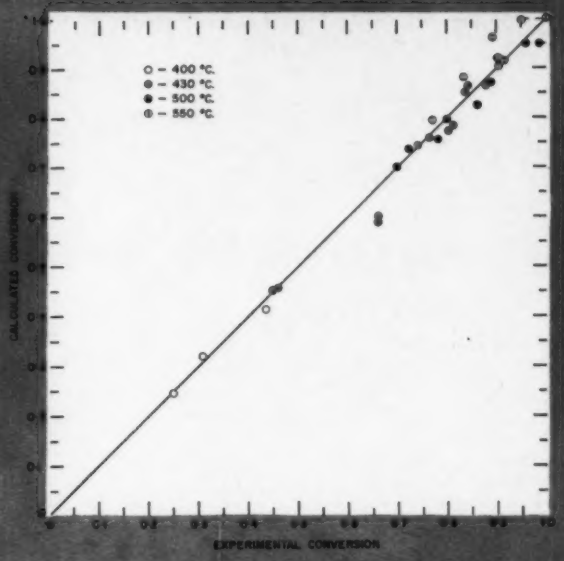


Fig. 13. Comparison of experimental and calculated results.

$$k = Ae^{-\frac{E}{RT}} \quad \ldots . (8)$$

The rate equations and their integrated forms, together with the values of A and E of Equation (8), are presented in Table II.

Selectivity Plots for Vinyl Chloride

For vinyl chloride, the method of approach described above did not lead to an acceptable rate equation. It was found useful to present the vinyl chloride conversions in terms of selectivity defined as:

$$s = \frac{x_1}{x} \quad \ldots . (9)$$

Plots of conversion to vinyl chloride vs. total conversion for the four temperatures are shown in Fig. 11. It is evident that in the range of conversions investigated, conversion to vinyl chloride is substantially independent of total conversion (i.e., space velocity). The slopes of these straight lines give the values of selectivity for the different temperatures; these values vary from unity at 400°C to about 0.92 at 550°C. When selectivity is plotted as a function of temperature on rectangular co-ordinates (Fig. 12), a straight line with the following equation is obtained:

$$s = 1.33 - 5.0 \times 10^{-4}T \quad \ldots . (10)$$

Combining Equation (10) with the rate and integrated equations for total conversion gives the corresponding equations for conversion to vinyl chloride; these equations are also included in Table II

TABLE II—Summary of Equations

1. *Overall Reaction*

$$r = k(1 - x)$$

$$\frac{1}{S_v} = \frac{1}{k} \ln \left(\frac{1-x}{1}\right)$$

2. *Conversion to Vinyl Chloride*

$$r = k[1 - x(1.33 - 5.0 \times 10^{-4}T)]$$

$$\frac{1}{S_v} = \frac{1}{k} \ln \left[\frac{1}{1-x(1.33-5.0\times10^{-4}T}\right]$$

3. *First-order Rate Constants*

(a) Low conversion range (up to 80%)

$$k = 1.45 \times 10^{20} e^{-\frac{59{,}000}{RT}}$$

(b) High conversion range 80–100%).

$$k = 9.8 \times 10^{7} e^{-\frac{20{,}000}{RT}}$$

In order to determine the accuracy of the equations presented in Table II, both overall and vinyl chloride conversions have been calculated from these equations and compared with the experimental values in Fig. 13. It can be seen that the agreement is good over the entire range of conversions and temperatures, the average error being about 2% and maximum error 8% (for two runs at 550°C).

Using the overall rate equations developed for the two regions of conversion, the problem of designing a coil-type reactor can be rigorously approached by the method originally proposed by Hougen and Watson[18] and subsequently elaborated by other investigators.[12, 22, 24, 28] The proposed selectivity correlation can then be used to predict conversion to vinyl chloride at any point in the reactor.

REFERENCES

1. Banerjee, S. C., and Doraiswamy, L. K. *Brit. Chem. Eng.*, 1958 **3**. 316.
2. Barton, D. H. R. *Nature*, 1946, **157**, 626; *Jour. Chem. Soc.*, 1949, 155.
3. Barton, D. H. R., and Howlett, K. E. *Jour. Chem. Soc.*, 1949, **148**.
4. Barton, D. H. R., and Mugdan, M. U.S. Pat. 2, 2,378,859, 1945.
5. Baxter, J. P., Edwards, W. A. M., and Winter, R. M. (to I.C.I.) B. Pat. 363,009, 1930.
6. Biltz, H. Ber. *Dtsch. Chem. Ges.*, 1902, **35**, 3524.
7. Biltz, H., and Küppers, Ber. *Dtsch. Chem. Ges.*, 1904, **37**, 2398.
8. Bobkov, S. S., and Shepenera, P. P. U.S.S.R. Pat. 66,688, 1946.
9. Chenney, H. A. (to Shell Development Co.). U.S. Pat. 2,569,923, 1951.
10. de Bataafsche Petroleum Maatschappij. Brit. Pat. 633,211, 1949.
11. Doraiswamy, L. K., and Pai. M. U. *J. sci. Ind. Res.*, 1956, **15B**, 87.
12. Fair, J. R. and Rase, H. F. *Chem. Eng. Prog.*, 1954, **50**, 415.
13. Farbwerke Hocht Vorm. Meister, Lucius and Bruning. D.R. Pat. 371,691; 408,926.
14. FIAT Final Report No. 843, p. 17.
15. Ghosh, J. C., and Guha, R. S. *Petroleum*, 1951, **14**, 261.
16. Heard, J. R. U.S. Pat. 2,393,367, 1946.
17. Hougen, O. A. "Reaction Kinetics in Chemical Engineering", A.I.Ch.E. Monograph Series, 2, 1952.
18. Hougen, O. A., and Watson, K. M. "Chemical Process Principles", John Wiley & Sons, New York, 1947.
19. I.G. Farben industrie A.G., F. Pat. 805,563, 1936; D.R. Pat. 585,793, 1933.
20. Kainer, F. *Kolloid Zeit.*, 1949, **113**, 121.
21. Kobe, K. A. *Petroleum Ref.*, 1957, **36**, 155.
22. Myers, P. S., and Watson, K. M. *Natl. Petroleum News, Tech. Sec.*, May 1, 1946, **38**, R 388; June 5, 1946, **38**, R 439.
23. Pavlovich, P. I., Trudy Konferentsii Uysokomolekulyar, Soedineniuam, Akad. Nauk. S.S.S.R., Otdel. Khim. Nauk i. Otdel Fiz—Mt. Mauk 1, 22 (1943) (Pub. 1945).
24. Schutt, H. C. *Chem. Eng. Prog.*, 1947, **43**, 103.
25. Senderens, J. B. *Bull. Soc. Chim. France*, 1908, p. 823.
26. Shell Development Co. F. Pat. 918,985.
27. Siggia, S. "Quantitative Organic Analysis via Functional Groups", 2nd edition, John Wiley & Sons, New York, 1954, p. 91.
28. Snow, R. H., and Schutt, H. C. *Chem. Eng. Prog.*, 1957, **53**, 133.
29. Solvay and Cie. B. Pat. 605,277, 1948.
30. Tatevskii, V. M., and Frost, A. V. *Vestnik Moskow Univ.*, 1947, No. 3, 65.
31. "Vinyl Chloride from Ethylene", *Petroleum Refiner*, 1953, **32**, 136.
32. Vlughter, J. C., Leenderste, J. J., and Mettivier-Meyer, R. H. *Chimica e Industria (Milan)*, 1951, **33**, 613.
33. Weiler, J. F. U.S. Pat. 2,412,308, 1946.

AN AUTOMATIC BACKWASHING CENTRIFUGE

IN the conventional automatic batch filtering centrifuge the periodic action of the unloading blade removes the outermost layers of the precipitated solids. The remaining layer of cake may be from 5-10 mm thick, which provides a good filtering medium. However, the filtration rate may be retarded, since very fine particles may be retained in this layer and upon the surface of the filter medium which may be finely woven metal cloth. The effect of these fine particles is shown also in the increased wetness of the discharged cake; for example, in some filtrations the moisture after six cycles has been known to be as high as 8%, which is scarcely better than would be achieved by a filter press operating upon the same material. After 7-8 cycles the solids may often be discharged as a paste instead of as a coherent cake.

In order to maintain the effective working of the automatic batch centrifugal, it is necessary to renew the underlayer in order to form a new layer free from the very fine particles which hinder the filtration. A centrifugal in which this renewal is carried out automatically has been described recently in the Russian chemical engineering literature.* One of the interesting features of this design is its basket. This consists of a frame, around which is wound wire of trapezoidal section, the section of the wire providing a clearance varying from 0.2 to 0.3 mm. The smaller parallel side of the wire section faces outwards. The second important feature of the centrifugal is the provision of travelling jets which direct high-pressure water or other suitable liquid through the outside of the rotating basket. The finer particles are thereby washed away, while most of the large particles remain in position upon the wire base.

To ensure that the area of the deposited cake is irrigated uniformly, the jets are caused to travel backwards and forwards over the full length of the basket by means of a servo motor (Fig. 1). Trials carried out with a centrifuge employing this system have shown that it fits in well with the operating cycle of batch automatic centrifugals. The particular machine (Russian model AG-600), separating a slurry containing 40% solids in suspension with the addition of 2.5% kaolin, operated according to the data shown in Fig. 2.

The thickness of the underlayer was 15 mm and the time to discharge the cake was 60 sec. The pressure at the travelling jets was 3 kg/cm², and the consumption 1.5 litres per sec. per nozzle. The nozzle diameter was 8 mm. From Fig. 2 it is clear that regeneration of the underlayer at every third cycle was enough to give a uniformly dry cake discharge. The regeneration operation took 40 sec.

A larger counterpart, incorporating both the new basket feature and the washing device back, had the following features (AG-1200-2Y):

Number of rpm	430
Basket diameter, mm	1180
Power of motor	12-13 hp
Basket capacity	240 l.
Total weight of machine ...	7600 kg.

The composition of the pulp used in tests upon this machine was as follows:

Sand	68%
Loam	Up to 2%
Water	Balance

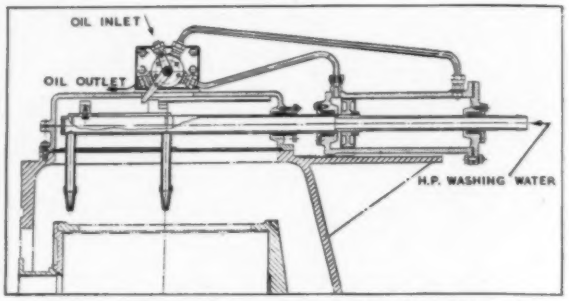


Fig. 1. Hydraulically - operated backwashing jet device.

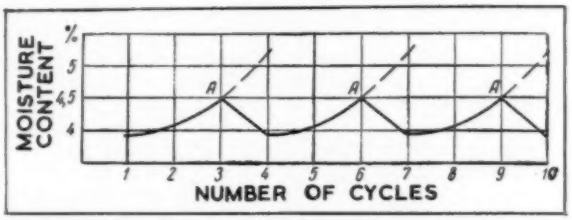


Fig. 2. Operation of centrifuge with regeneration of underlayer. Backwashing performed at every third cycle (points marked A).

Pressure of water at jet	6 kg/cm²
Quantity of water for removal of very fine particles	23.5 gm/l.

With the feed of the above composition regeneration was found necessary after every cycle, and the following schedule was observed:

Charging	20 sec.
Cake forming	60 sec.
Discharging cake	25 sec.
Regeneration of underlayer ...	60 sec.
Total time of cycle	2 min. 45 sec.

In operation this gave:

Thickness of layer of sand ...	85 mm
Thickness of underlayer	8 mm

During a trial run of 100 hr the output averaged 4600 kg/hr of sand dried to 3.8-4.8% of moisture. In this period the blades for unloading the sediment precipitate cake were renewed once. The level regulating rake was also renewed once during this run.

From the results of this run and other similar tests the materials recommended for the construction of these components is unmachined cast iron instead of mild steel.

The slow speed of rotation for the pulp used in the tests is due mainly to the good filtering qualities of the slurry and in these conditions wear and tear of the blades and rake was negligible.

For other more-difficult-to-filter precipitates such as polyethylene, a greater speed of rotation is necessary; in such cases, the pressure of the regeneration water supply should be raised to 8-10 kg/cm²

* *Khim. Mash.* (Chemical Plant Construction), 1959 No. 5, 1-3.

66.074.327

Nitrogen adsorption dryer at Margam, South Wales.
(Photo by courtesy of Burnett & Lewis Ltd.)

PART III | ADSORPTION DRYING OF GASES

by J. W. CARTER, B.Sc. (Lond.), F.R.I.C., A.M.I.Chem.E.

IN Part II last month, details of the important methods of predicting outlet concentration-time curves for fixed beds were given, showing how they take into account the various mechanisms involved. Predictions by these methods are now compared against experimental values for isothermal adsorption of water vapour from air flowing through a silica gel column. Then, Rosen's method is applied when adiabatic conditions and low "contact times" occur for an air flow dried by a tower of activated alumina. Reactivation of an adsorber and the effect of the presence of adsorbates in addition to water are also briefly discussed.

Each of the analyses now outlined of transient mass transfer in fixed adsorber beds account for the rate controlling operations in different days. That of Hougen and Marshall[19] is perhaps the simplest and describes the combined resistances in the granules and fluid boundary layer in terms of an overall film coefficient which is a function of the gas flow.[17, 66] In Eagleton's method the separate "solid film" mass transfer coefficient is at least independent of the gas flow rate. However, for describing mass transfer through spherical bodies the concept of a mass transfer coefficient is suggested[7] as being accurate only in the later stages of saturation, after 40% of the equilibrium conditions has been reached. Rosen's[12, 13] treatment assumes a constant value of the adsorbed phase diffusion coefficient over the whole range of adsorption, which may seem presumptious for the relatively immobile monomolecular layer region if this form of transport is important. These approximations are restrictive in the usefulness of the various methods and it is therefore most instructive to compare them for practical cases. In the first instance it is proposed to use as a basis of comparison Eagleton's[66] run *S*2, drying atmospheric air with silica gel, referred to by Treybal on page 508 of his book. The variation in outlet moisture vapour concentration will also be determined by Michael's method, outlined by Treybal, so that this will also be compared with the other treatments. In each set of the calculations that follow, the essential steps have been given and reference to the appropriate paper is desirable if it is required to follow a more detailed treatment.

The conditions of Eagleton's experiment were as follows:

Bed Details: i.d. = 0.628 in. Height = 1 ft. Weight = 40.65 gm Particle size = 0.056–0.079 in. (average = 0.00567 ft). Bulk density = 41.9 lb./ft³. Granule density = 79 lb./ft³. Granule area = 445 ft²/ft³. *Air Flow:* Rate = 95.5 lb./hr/ft². Inlet humidity = 0.00267 lb./lb. Temp. = 80°F. Density = 0.074 lb./ft³. Pressure = 768.2 mm Hg.

Because of the small diameter bed and low inlet humidity, operation can be considered isothermal.

Michael's Method[3]

Treybal's example of this method uses Eagleton's correlations to derive an overall mass-transfer coefficient. Flow conditions are identical with run S_2, but he has used a 2-ft-deep bed instead of 1 ft for his calculations. Also, his Henry's Law relationship for the isotherm is applicable only to the lower part of the isotherm and not over the full range up to the inlet humidity. The steps in the calculation are given below using the same breakpoint and exhaustion humidity values as Treybal, namely, $y_b = 0.0001$ lb./lb. and $y_e = 0.0024$ lb./lb., to define the adsorption wave.

Using Fig. 4, showing the adsorption isotherm:

$$L_s = \text{solids rate} = \frac{y_0.G}{x_t} = \frac{0.00267}{0.084} \times 95.5 = 3.03 \text{ lb./hr. ft}^2;$$

Gas film mass transfer coefficient $= k_g a = 188 \times 95.5^{0.55}$

$= 2310$ lb./hr ft³ $\therefore H_g = \dfrac{G}{k_g a} = \dfrac{95.5}{2310} = 0.0413$ ft.

$=$ Htu (gas film)

Solid film mass transfer coefficient $= k_s a = 217$ lb./hr ft³

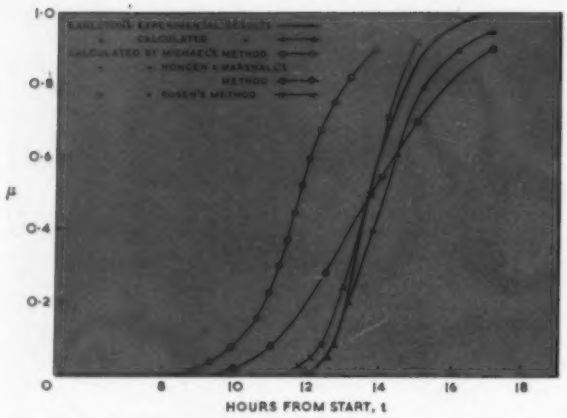


Fig. 5. Calculated break-through curve for Michael's method.

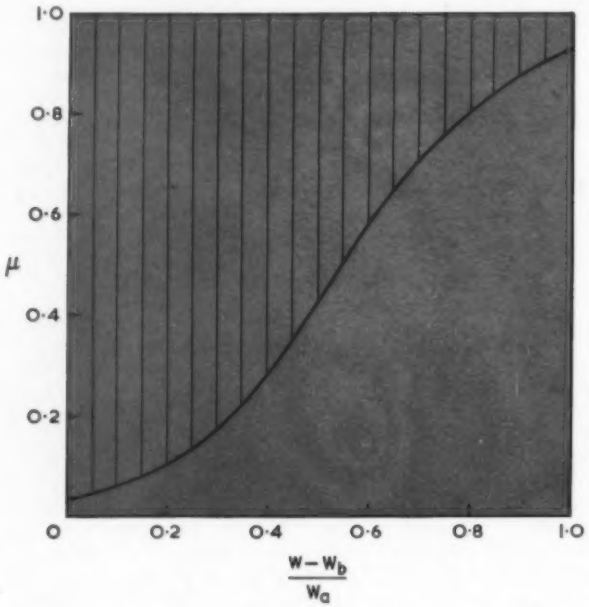


Fig. 6. Variation of outlet concentration with time. Eagleton's run S₂.

$$\therefore H_s = \frac{L_s}{k_s a} = \frac{3.03}{217} = 0.0137 \text{ ft} = \text{Htu (solid film)}$$

$$\text{then } H_{tog} = H_g + \frac{C.G}{L_s} . H_s . = 0.0413 \times \frac{0.00267 \times 95.5}{0.084 \times 3.03} \times 0.0137 = 0.055 \text{ ft} = Htu \text{ (overall gas film).}$$

The summary of the calculation of the number of transfer units in the absorption zone, $N_{tog} = \int_{y_B}^{y} \frac{yd}{y - y^x}$, is given in Table III.

$$\text{According to Treybal, } \frac{W - W_b}{W_a} = \frac{\int_{y_b}^{y} \frac{dy}{y - y^x}}{\int_{y_b}^{y_e} \frac{dy}{y - y^x}} = \frac{\text{No. of transfer units up to } y}{\text{No. of transfer units in the adsorption wave.}}$$

where W = lb. dry effluent air up to outlet humidity, y;
W_b = lb. dry effluent air up to outlet humidity, y_b (break point); and
W_a = lb. dry effluent air up to outlet humidity between y_b and y_e (break and exhaustion points).

The fifth column of Table III is thus obtained by dividing the value of the number of transfer units in column four by 10.950. These are plotted against u in Fig. 5 to give the break-through curve for the adsorption zone, the hatched portion representing the fractional ability of the zone still to adsorb. Integrating graphically, the average value for the zone is 0.546.

Thus the fractional saturation of a bed Z ft. deep at the breakpoint $= \frac{Z - Z_a \times 0.546}{Z} = 1 - 0.546 Z_a$ for a 1 ft bed

where Z_a = depth of the adsorption zone $= N_{tog} \times H_{tog} = 10.95 \times 0.055 = 0.60$ ft.

$\therefore$ degree of saturation at break point $= 1 - 0.564 \times 0.60 = 0.673 = \frac{\text{Actual weight of water in bed}}{\text{Weight at Saturation}}$

$\therefore$ Actual amount of water adsorbed by bed/ft² cross-section $= 41.9 \times 0.084 \times 0.673 = 2.37$ lb.

Thus, the time to reach break point $= t_b = \frac{2.37}{95.5 \times .00267} = 9.3$ hr.

If the bed is in equilibrium with the inlet air humidity, the water adsorbed $= 41.9 \times 0.084 = 3.52$ lb.

$\therefore W_a = \frac{3.52 - 2.37}{0.00267} = 431$ lb. air/ft² and $\therefore t_a = \frac{431}{95.5} = 4.5$ hr.

Then the total time from the start to reach the appropriate value of the outlet concentration $= t = t_a + t_b \left(\frac{W - W_b}{W}\right)$.

The values of t in the last column of Table III are plotted against u with Eagleton's experimental values in Fig. 6. The forecast of the break point by this method is over 2½ hr early, but the slower increase of outlet humidity reduces the discrepancy to approximately 1½ hr at exhaustion point. Eagleton's calculated outlet concentration wave, taken from his thesis[45] and using his isotherm equation, is also shown, giving a much closer prediction, particularly at the break point. The divergence of Michael's method here from Eagleton's curves is partly due to using mass transfer coefficients with the actual isotherm curve, although the calculation of these coefficients is based on a straight line, in addition to the approximations of the method itself.

Hougen and Marshall's Method[17]

$$H_{tog} = \frac{1.42}{a}\left(\frac{d_p G}{\mu}\right)^{0.51} = \frac{1.42}{445}\left(\frac{0.00567 \times 95.5}{0.018 \times 2.42}\right)^{0.51} = 1.15 \times 10^{-2} \text{ ft.}$$

$$\therefore gz = \frac{1}{1.15 \times 10^{-2}} \times 1 = 87; \quad C = \frac{0.00267}{0.084} = 0.0318$$

$$b = \beta C = \frac{G.C}{\rho_B . H_{tog}} = \frac{95.5 \times 0.0318}{41.9 \times 1.15 \times 10^{-2}} = 6.30.$$

The values of u in Table IV are determined from Hougen and Marshall's curves[17] and are also plotted in Fig. 5.

In the earlier stages of the break-through curve, when the adsorbent is very little saturated, it is to be expected that mass transfer across the gas film would be controlling. The earlier break point and shallower gradient of the Hougen and Marshall curve is thus the result of using too low an

TABLE III

y	y^*	$\frac{1}{y-y^*}$	$\int_{y_b}^{y}\frac{dy}{y-y^*}$	$\frac{W-W_0}{W_a}$	$u=y/y_0$	$t=t_0+t_a\left(\frac{W-W_0}{W_a}\right)$
$y_b = 0.0001$	0.00005	20,000	0	0	0.0375	9.3 hr
0.0002	0.00010	10,000	1.500	0.137	0.075	9.9
0.0004	0.00022	5,550	3.055	0.279	0.150	10.6
0.0006	0.00032	3,570	3,967	0.362	0.225	10.9
0.0008	0.00046	2,940	4,618	0.422	0.300	11.2
0.0010	0.00062	2,630	5,175	0.473	0.374	11.4
0.0012	0.00077	2,220	5,660	0.517	0.450	11.6
0.0014	0.00100	2,500	6,132	0.560	0.525	11.8
0.0016	0.00128	3,120	6,694	0.612	0.599	12.1
0.0018	0.00153	3,700	7,376	0.674	0.674	12.3
0.0020	0.00179	4,770	8.223	0.751	0.750	12.7
0.0022	0.00204	6,250	9.325	0.852	0.825	13.1
$y_a = 0.0024$	0.00230	10,000	10.950	1.000	0.899	13.8

overall mass transfer coefficient. Later it is more likely that diffusion in the granules would be controlling, because of the lower adsorbed phase concentration gradients as saturation approaches. The rate of mass transfer then predicted by these authors' formula will be too high, giving an outlet concentration curve lagging behind the actual one.

Rosen's Method[12,13]

$$\text{Porosity of bed} = \frac{\text{pore volume}}{\text{bulk volume}} = \frac{1-41.9/79}{1} = 0.47.$$

$$\therefore m = \frac{0.47}{1-0.47} = 0.89.$$

$$\text{Air flow} = 95.5 \text{ lb./hr/ft}^2 = \frac{95.5}{0.074 \times 3600} = 0.359 \text{ fps.}$$

$$\therefore v = 0.359/0.47 = 0.765 \text{ fps.}$$

$$\text{Henry's Law coefficient} = K = q_s/c$$

$$= w_1/y_o \; x \; \rho_{\text{granule}}/\rho_{\text{air}} = \frac{0.084 \times 79}{0.00267 \times 0.074} = 0.336 \times 10^5$$

$$h = \frac{k_g}{\rho_{\text{air}}} \therefore \frac{1}{R_f} = \frac{3h}{b} = \frac{3k_g}{\rho_{\text{air}} b}$$

Now using curve 7, page 54 of *Mass Transfer* (Treybal), to determine k_g:

$$\text{Re}'' = \frac{d_p.G}{\mu} = \frac{0.00567 \times 95.5}{0.018 \times 2.42} = 12.4$$

$$j_d = 0.54 = \frac{k_g \times \text{Sc}^{2/3}}{G} = \frac{k_g \,.\, 0.60^{2/3}}{95.5} : \text{Sc} = \text{Schmidt group.}$$

$$\therefore k_g = \frac{0.54 \times 95.5}{0.71} = 72.6 \text{ lb./hr ft}^2.$$

$$\therefore \frac{1}{R_f} = \frac{3 \times 72.6}{3600 \times 0.074 \times 0.00283} = 289 \text{ sec.}^{-1}.$$

It is now possible to calculate the dimensionless bed length parameter. For the solid diffusion coefficient it is proposed to take a value of 2×10^{-8} ft^2/sec. Values of this order have been published by Carman[67] and Haul[43c] for a coverage of one monolayer on heterogeneous materials such as silica. Any contribution from gas phase flow in the pores is considered negligible.

$$x = \frac{3DKz}{mvb^2} = \frac{3 \times 2 \times 10^{-8} \times 0.336 \times 10^5 \times 1}{0.89 \times 0.765 \times 0.00283^2} = 370$$

This is a large value, the largest tabulated by Rosen[13] being 40.0, and thus Equation (15) of his paper can be applied. Since the ratios y/x and v/x are used, u is sensibly independent of D at these values of x.

Rosen's equation[15] is $u = \frac{1}{2} + \frac{1}{2}$ erf E and thus erf $E = 2u - 1$ where erf E = error function of E and $E = \frac{3/2\,(y/x) - 1}{2\sqrt{V/x}}$ thus $y/x = (2E\sqrt{V/x} + 1)^{2/3}$

TABLE IV

t hours	$b.t.$	$u=y/y_0$
10	63	0.02
11	69.3	0.08
12.5	79	0.28
14	88.2	0.55
15	94.5	0.70
17	107.1	0.9

TABLE V

$u = c/c_0$	$2u-1 =$ erf E	E	$y/x =$ $0.0647E + 0.667$	$t =$ $(y/x) \times 20.55$ hr
0.024	−0.9523	−1.40	0.576	11.8
0.045	−0.9103	−1.20	0.589	12.1
0.079	−0.8427	−1.00	0.602	12.4
0.24	−0.5205	−0.50	0.635	13.0
0.50	0	0	0.667	13.7
0.715	0.4284	0.40	0.693	14.2
0.92	0.8427	1.00	0.732	15.0

TABLE VI

u	y/x	$t = (y/x)$ 8.55 hr
0.04	0.3	2.4
0.074	0.25	2.95
0.261	0.50	4.3
0.429	0.60	5.1

TABLE VII

y/x	u	$t = (y/x)$ 1.48 hr
0.15	0.074	0.22
0.35	0.290	0.51
0.45	0.397	0.66
0.57	0.512	0.84

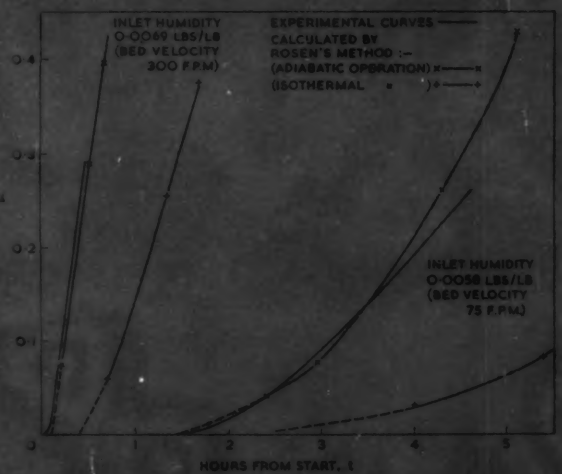


Fig. 7. Variation on outlet concentration with time. MOA tests at inlet humidities 0.0058 lb./lb. and 0.0055 lb./lb.

$$y/x = \left(\frac{2m}{3k}\right)\left(\frac{vt}{z} - 1\right)$$

$$= \left(\frac{2 \times 0.89}{3 \times 0.336 \times 10^5}\right)\left(\frac{0.765 \times 3600 \times t}{1} - 1\right) : t = \text{hours.}$$

$$\therefore t = \left[(y/x)\frac{3 \times 0.336 \times 10^5}{2 \times 0.89} + 1\right] /0.765 \times 3600$$

$$= (y/x \times 20.55) \text{ hr.}$$

$$V/x = \frac{mv\,R_f}{2} = \frac{0.89 \times 0.765 \times 1/289}{1} = 0.236 \times 10^{-2}$$

Thus $y/x = \frac{1}{2}(2E\sqrt{(0.236 \times 10^{-2})} + 1) = (0.0647E + 0.667)$.

Using values of the error function from tables, it is now possible to calculate y/x, and thus t, for required values of the outlet concentration u. Table V summarises this for a range of values, also plotted in Fig. 6 with the previous curves.

The accuracy of prediction of outlet concentration is at least equal to Eagleton's and a considerable improvement on Michael's and Hougen and Marshall's methods. It should be noted that if the effect of D was not negligible the break point would have occured earlier and the curve would have been less steep.

The small effect of solid diffusion was due to the combination of a low flow-rate and small adsorbent granules. Also, since the conditions in the bed were essentially isothermal, it will be shown that Rosen's method can be used for adiabatic conditions, and where diffusion in the granules is important or even controlling. For this purpose the results of tests carried out by the Ministry of Aviation[68] in a 2½ ft square by 2½ ft deep bed of ¼–½-in. activated alumina will be used. This series is one of a number forming the basis of Rathmell and Bateman's paper.[20] The two curves chosen are the results of experiments at quite different air flow-rates, each considerably higher than that used by Eagleton.

M.O.A Test — Inlet Humidity 0.0058 lb/lb

Bed Details: Dimensions = 2½ × 2½ × 2½ ft high. Weight = 540 lb. Particle size = ¼–½-in. (0.031 ft average). Bulk density = 38 lb./ft³. Granule density = 72 lb./ft³. *Air Flow:* Rate = 348 lb./hr ft² (75 fpm). Inlet temperature = 53°F. Density = 0.0773 lb./ft³. Pressure = atmospheric.

Preliminary calculations using a bed temperature of 53°F showed that the assumption of isothermal conditions is incorrect. Temperature measurements during adsorption were also reported and gave a maximum value of 80 in the bed. This has been used to calculate the Henry's law coefficient from manufacturers' equilibrium data.[69]

Thus, $K_{82°F} = 0.215 \times 10^5$.

Bed porosity $= 1 - 38/72 = 0.47$;

$$\therefore m = 0.47/1 - \frac{0.47}{1-0.47} = 0.89$$

$$v = \frac{75}{60 \times 0.47} = 2.66 \text{ fps.}$$

Using the previous value for D of 2.0×10^{-8} ft²/sec.

$$x = \frac{3DVz}{mvb^2} = \frac{3 \times 2 \times 10^{-8} \times 0.215 \times 10^5 \times 2.25}{0.89 \times 2.66 \times 0.0155^2} = 5.1$$

Because of this low value, Rosen's curves and tabulated values will be used instead of his simplified solution as before.

$$\text{Re}'' = \frac{0.031 \times 348}{0.018 \times 2.42} = 240: j_d = 0.12 \quad \therefore k_g = \frac{0.12 \times 348}{0.71}$$

$$= 58.8 \text{ lb./hr ft}^2$$

$$\text{thus } h = \frac{58.8}{3600 \times 0.0773} = 0.211 \text{ ft/sec. and } \frac{1}{R_f} = \frac{3h}{b}$$

$$= \frac{3 \times 0.211}{0.0155} = 40.8 \text{ sec.}^{-1}$$

$$\text{then } V/x = \frac{mvR_f}{z} = \frac{0.89 \times 2.66 \times 1/40.8}{2.25} = 0.026$$

$$\text{and } y/x = \left(\frac{2m}{3K}\right)\left(\frac{vt}{z} - 1\right)$$

$$= \left(\frac{2 \times 0.89}{3 \times 0.215 \times 10^5}\right)\left(\frac{2.60 \times 3600 \times t}{2.25} - 1\right):$$

$$\text{and } t = (y/x)\ 8.55 \text{ hr.}$$

For $x = 5.0$ and $V/x = 0.025$, Table VI is obtained from Rosen's tables and curves.

These results are plotted in Fig. 7 against the experimental values and show quite a reasonable agreement. The curve calculated on the assumption of isothermal operation is also shown.

M.O.A. Test — Inlet Humidity 0.0069 lb/lb

Bed Details: as before. *Air Flow:* 1375 lb/hr ft² (300 fpm). Inlet temperature = 55°F. Density = 0.0765 lb./ft³. Pressure = atmospheric. Measured bed temperature = 90°F. $K_{90°F} = 0.149 \times 10^5$.

$$v = \frac{300}{60} \times \frac{1}{0.47} = 10.65 \text{ fps.}$$

$$\text{Re}'' = \frac{0.031 \times 1375}{0.18 \times 2.42} = 946; j_d = 0.06$$

$$\therefore k_g = \frac{0.06 \times 1375}{0.71} = 116 \text{ lb./hr ft}^2; \text{ thus } h = \frac{116}{3600 \times 0.0765}$$

$$= 0.42 \text{ ft/sec.}$$

$$\text{and } 1/R_f = 3h/b = \frac{3 \times 0.42}{0.0155} = 81.7 \text{ sec.}^{-1}.$$

$$\text{Also } x = \frac{3DKz}{mvb^2} = \frac{3 \times 2.0 \times 10^{-8} \times 0.149 \times 10^5 \times 2.25}{0.89 \times 10.65 \times 0.0155^2}$$

$$= 0.89$$

$$\text{thus } V/x = \frac{mvR_f}{z}\ \frac{0.89 \times 10.65 \times (1/81.7)}{2.25} = 0.051$$

$$\text{and } y/x = \left(\frac{2m}{3}\right)\left(\frac{vt}{z} - 1\right)$$

$$= \left(\frac{2 \times 0.89}{3 \times 0.149 \times 10^5}\right)\left(\frac{10.65 \times t \times 3600}{2.25} - 1\right):$$

$$t = (y/x)\ 1.48 \text{ hr.}$$

for $x = 1.0$ and $u/x = 0.05$, (y/x) and thus t is obtained in Table VII.

This outlet concentration curve, also shown in Fig. 7, gives a break point approximately 2 minutes late and, although this is a large proportion of the total time up to this stage, the discrepancy would be partly corrected by interpolation of the tabulated results between $x = 0.5$ and 1.0.

The close prediction of these two experimental curves is a strong recommendation for a method which takes into account all the important mechanisms, in spite of the approximations inherent in using a linear isotherm and a constant solid phase diffusion coefficient. The measured bed temperatures, used for determining the equilibrium curve coefficients, may be calculated approximately using the heat of adsorption of 1250 Btu/lb.[29] If it is assumed that all this heat is absorbed by the air flow, the maximum temperatures in each of the previous experiments would be respectively

$$(53 + 0.0058 \times 1250/0.238) = 83\tfrac{1}{4}°\text{F and}$$

$$(55 + 0.0069 \times 1250/0.238) = 91°\text{F.}$$

This assumption is not unreasonable, since the heat capacity of the adsorbent bed is usually small compared with that of the total air that has passed through it. Also, a large

proportion of the heat generated at the surface of a granule will be transferred to the air flow, giving a falling temperature gradient towards the centre of the particle. This picture will be modified by the effect of flow rate, and variation in heat of adsorption with coverage. Perhaps the most significant point illustrated by the break-through curves in Fig. 7 is the considerable advantage of operating under isothermal conditions, if they could be achieved economically.

Design of Fluidised Bed Adsorbers

Only brief reference will be made to this aspect of gas dehydration, partly because of the complexity of the processes in gas fluidised beds, and also since only one set of useful results has been published.[32] Mass transfer coefficients in fluidised beds, for a range of systems, have been correlated by Chu *et al.*[70] as j_d factors. These give higher rates than those of Cox[32] for water vapour adsorption from air by silica gel beads, suggesting significant resistance to adsorbed phase transport. It is also of interest that Cox's mass transfer coefficients, based on thorough mixing of the solid and no back mixing of the gas, increase unpredictably with decreasing bed depth. The reason is indicated in work by Heertjes[30] and Richardson and Bakhtiar,[71] who find that virtually all the transfer probably takes place in a shallow zone at the bottom of the bed. This effect of bed depth is at variance with Chu's correlation and needs further investigation.

Reactivation of Fixed-bed Adsorbers

A number of authors[64, 72, 73, 74] have published theoretical and experimental investigations of heat transfer in packed beds, and once the temperature to which an adsorbent has to be heated is decided, these may be applied using the appropriate method of heating. Frequently, the most difficult problem is to decide the lowest economical temperature suitable for the operating conditions. The effect of regeneration temperature on water adsorption capacity and efficiency is given for molecular sieves,[59] while the manufacturers of silica gel and alumina recommend that a minimum of approximately 150°C and 200°C respectively is desirable. Because of the wastefulness of raising the adsorbent temperature at all, unfortunately unavoidable, more information on this subject is necessary.

Due to the evaporation of adsorbed water during the heating portion of a regeneration cycle, the above methods of calculation will not be easily applicable, and may perhaps require a tedious stepwise trial-and-error approach.[75] It is quite usual in practice to base reactivation requirements on a heat balance, using either an efficiency factor or outlet air flow temperature based on experimental work to allow for losses. For heating, this factor may be as low as 0.5 and examples of such calculations are given in Hougen and Dodge.[61] It is worth noting, that for convective heat transfer in packed beds, where the granules have poor heat conduction properties and the gas film is not controlling, there is no reason why Rosen's curves[13] should not be suitable, using the thermal instead of mass diffusivity of the solid. Again, they would be more suitable for the cooling rather than the heating period.

Adsorption Drying in the Presence of Other Adsorbable Components

Although air and similar gases have no serious effect on the water adsorption capacity of silica gel, activated alumina and molecular sieves, this is not true for hydrocarbons and other condensable gases. Saturated hydrocarbons from about the C_4's upwards are appreciably adsorbed, in addition to unsaturated compounds such as acetylene and ethylene, dependent upon their partial pressures in the gas phase. Also, there may be impurities such as hydrogen sulphide and organic sulphur compounds which are adsorbable, and the effect on the water capacity of this competition has in all cases to be assessed in determining the adsorber size. The property of molecular sieves of excluding large molecules is particularly useful for some of these applications.

Equilibria studies[5, 7, 76] of binary mixtures show the effect of gas phase composition on the amount of each component adsorbed. The systems studied have been mainly hydrocarbon gases on silica gel and activated charcoal, the results being plotted in a form similar to the x-y diagram for vapour-liquid equilibria, showing the molar composition of the adsorbed phase against gas phase composition. Prediction of such curves has been most successful using an empirical relationship known as the capacity fraction equation,

$$\frac{N_A}{N_A'} + \frac{N_B}{N_B'} = 1:$$

N_A and N_B = mols adsorbed from gas mixture of A and B respectively.

N_A' and N_B' = mols adsorbed of A and B respectively from pure component at pressure equal to total of mixture A and B.

The limitations of this relationship have not been fully explored, but its application to vapour mixtures of polar and non-polar molecules such as water and hydrocarbons must be suspect in the absence of experimental evidence. However, where two similar vapours in an inert gas are involved, by ignoring the presence of the latter it is possible that the capacity fraction equation could be used to calculate the binary equilibria on the solid using single-component data.

This equation predicts that in a fixed bed the less strongly adsorbed component will be displaced, giving a peak in the outlet concentration. Strongly polar molecules such as water will in any case desorb the majority of hydrocarbons on adsorbents such as silica gel, activated alumina and molecular sieves as the water absorption band moves along the column. This is shown very effectively by Ku *et al.*[77] drying gas containing hexanes and heptanes using various aluminas. The variation of hydrocarbon outlet composition with time that occurs is such that it may have to be taken into account in subsequent processes.

Adsorption of components in addition to water vapour may also affect the reactivation of a saturated adsorbent. If a large amount of hydrocarbons still remain adsorbed, these will have to be evaporated during the heating cycle, and possibly recovered, so that the reactivation equipment will have to be designed accordingly. During heating, hydrolysis of adsorbed vapours such as carbon oxysulphide and chlorinated hydrocarbons will occur, in some instances catalysed by the adsorbent, so that objectionable, and perhaps corrosive, gases have to be disposed of. Also, unsaturated hydrocarbons such as acetylene, ethylene and particularly isoprene, polymerise on the adsorbent surface during heating, causing a marked reduction in water adsorption capacity. Although the useful life of the desiccant is limited in such circumstances, it can be extended by partly desorbing at relatively low temperatures, using an inert gas for purging, before the normal heating cycle is carried out. This may be combined with an occasional high-temperature reactivation to remove some of the polymers that have formed.

Conclusion

This paper has used the narrow field of adsorption drying of gases as a background to discuss methods proposed for mass transfer operations in fixed beds and it is intended that other systems, for example, organic vapour recovery by activated charcoal, will also be explored in due course. The data presented indicate that Rosen's treatment has possibilities as a useful tool in predicting the performance of these hitherto difficult systems. However, where adiabatic opera-

List of Symbols

a = external area of adsorbent particles (ft²/ft³);
b = effective particle radius (ft), Rosen's method; or $\beta . C$. Hougen and Marshall's method; or constant in Langmuir's equation;
C = Henry's law isotherm constant, Hougen and Marshall's method;
c = concentration of adsorbate in gas (volumetric); or constant in the B.E.T. equation;
c^* = concentration of adsorbate in gas (volumetric) in equilibrium with q_s;
D = effective diffusion coefficient of adsorbate in particles (ft²/sec.²);
D_L = longitudinal diffusion coefficient in gas phase (ft²/sec.);
d_p = effective particle diameter (ft);
G = mass velocity (lb./hr ft²);
$g = \frac{1}{H_{tog}}$ (1/ft.);
H_{tog} = H.T.U. based on overall gas film (ft);
H_g = H.T.U. based on gas film;
H_s = H.T.U. based on "solid film";
h = gas film mass transfer coefficient (ft/sec), Rosen's method;
j_d = j factor for mass transfer (see Treybal, reference 3);
K = Henry's law isotherm constant, Rosen's method;
k_g = gas film mass transfer coefficient (lb./hr ft²);
k_s = solid mass transfer coefficient (lb./hr ft²);
L_s = solids rate (lb./hr ft²);
m = void volume of adsorbent;
N_{tog} = number of transfer units based on overall gas film;
n = maximum number of layers of molecules adsorbed in a pore;
p = equilibrium vapour pressure of adsorbate;
p_a = equilibrium vapour pressure of adsorbate during adsorption;
p_d = equilibrium vapour pressure of adsorbate during desorption;
p_0 = saturated vapour pressure over plane liquid surface at isotherm temperature;
q = average concentration of adsorbate on adsorbent particles (volumetric);
q_i = concentration of adsorbate in particle at radius r (volumetric);
q_s = concentration of adsorbate on particle surface (volumetric) in equilibrium with c^*;
R_f = surface film resistance (sec.) = $b/3h$, Rosen's method;
r = radial distance from particle centre (ft), Rosen's method; or pore radius for capillary condensation formulæ;
Z = bed depth;
t = time (sec. or hr);
t_a = time between arrival of break and exhaustion points;
t_b = time from start to breakpoint;
V = volume of gaseous adsorbate;
V_m = volume of gaseous adsorbate to form a monomolecular layer;
v = linear flow velocity (ft/sec.);
v_m = molar volume of liquid adsorbate;
W = quantity of dry air (lb);
W_b = quantity of dry air up to y_b (lb.);
W_a = quantity of dry air between y_b and y_e (lb.);
w = average adsorbate concentration in particles (lb./lb.);
w_s = adsorbate concentration at granule surface (lb./lb.)—in equilibrium with y_s;
x = solid phase adsorbate concentration (lb./lb.) in equilibrium with y_0;
y = adsorbate concentration in gas phase (lb./lb.);
y^+ = adsorbate concentration in gas phase in equilibrium with w (lb./lb.);
y_b = adsorbate concentration in gas phase at break point (lb./lb.);
y_e = adsorbate concentration in gas phase at exhaustion (lb./lb.);
y_0 = adsorbate concentration in inlet gas phase (lb./lb.);
y_s = adsorbate concentration in gas phase (lb./lb.) in equilibrium with w_s;
z = height of bed (ft);
z_a = height of adsorption zone (ft);
V = film resistance parameter (Rosen = $3\,DKR_f/b^2$ (dimensionless);
x = bed length parameter (Rosen) = $3\,DK\,z/mvb^2$ (dimensionless);
y = contact time = $2\,D(t - z/v)/b^2$ (dimensionless);
gz = thickness modulus (Hougen and Marshall) (dimensionless);
bt = time modulus (Hougen and Marshall) (dimensionless);
$Re'' = d_p.G/\mu$ = Reynolds number based on d_p;
$Sc = \mu/\rho.D$ = Schmidt number;
α = angle of wetting of pores by liquid adsorbate;
$\beta = \frac{G}{B\,H_{tog}}$;
ϵ = Polanyi's adsorption potential;
μ = gas flow absolute viscosity;
ρ_B = bed bulk density (lb./ft³);
ρ_{air} = air flow density (lb./ft³);
$\rho_{granule}$ = granule density (lb./ft³);
σ = surface tension of liquid adsorbate;
erf = error function. (See tables in Jahnke und Emde. Dover Publications.)

tion occurs the simplified calculation of the bed temperature would require improvement or additional justification before accepting its general practical validity. There is, of course, a shortage of information on adsorption diffusion coefficients for vapours and granular adsorbents, but it is worth noting that, as in the example from Eagleton's work, there will be many cases where solid diffusion is of little importance. In such instances it would appear that existing correlations of mass transfer coefficients and the experimental adsorption isotherm for the appropriate temperature are sufficient.

REFERENCES

[1] Harper, J. L., Olsen, J. L., and Shuman, F. R. *Chem. Eng. Progress*, 1952, **48**, 276.
[2] "Sorption Processes", *Chem. Eng. Progress*, 1957, **53**, 513.
[3] Treybal, R. E. "Mass Transfer Operations". McGraw-Hill, 1955.
[4] Brown, G. G. "Unit Operations", Wiley & Sons, 1950.
[5] Garner, F. H., Ellis, S. R. M., Steer, D. C., and Thompson, D. W. Conf. Europiene de Genie Chimique, Paris, November 24, 1956.
[6] Mair, J. H., Westhaver, J. W., and Rossini, F. D. *Ind. Eng. Chem.*, 1950, **42**, 1279.
[7] Calderbank, P. H., and Mackrakis, N. S. *Trans. Inst. Chem. Engrs*, 1956, **34**, 321.
[8] Lowan, A. N. *Phil. Mag.*, 1934, **7**, 914.
[9] Wicke, E. *Kolloid Z.*, 1939, **86**, 295.
[10] Thomas, H. C. *J. Chem. Phys.*, 1951, **19**, 1213.
[11] Kasten, P. R., Lapidus, L., and Amundson, N. R. *J. Ph. Ch.*, 1952, **56**, 683.
[12] Rosen, J. B. *J. Chem. Phys.*, 1952, **20**, 387.
[13] Rosen, J. B. *Ind. Eng. Chem.*, 1954, **46**, 1590.
[14] Glueckauf, E., and Coates, J. I. *J. Chem. Soc.*, 1947, p. 1315.
[15] Heister, N. K., and Vermeulen, T. *Chem. Eng. Progress*, 1952, **48**, 505.
[16] Vermeulen, T. *Ind. Eng. Chem.*, 1953, **45**, 1664.
[17] Eagleton, L. C., and Bliss, H. *Chem. Eng. Progress*, 1953, **49**, 543.
[18] Jury, S. H., and Licht, W. *Chem. Eng. Progress*, 1952, **48**, 102.
[19] Hougen, O. A., and Marshall, W. R. *Chem. Eng. Progress*, 1947, **43**, 197.
[20] Klinkenberg, A. *Ind. Eng. Chem.*, 1948, **40**, 1992.
[21] Johansson, C. H., Persson, G., and Svensson, B. *Acta, Polytech.* No. 29 (Chem. Met. Ser. 1, No. 7), p. 5, 1949.
[22] Goldstein, S. *Proc. Roy. Soc.*, 1953, A219, 151.
[23] Offord, A. C., and Weiss, J. *Disc. Far. Soc.*, 1949, No. 7, 26.
[24] Sillen, L. G. *Arkiv Kemi*, 1950, Band 2, No. 35.
[25] Thomas, H. C. *Ann. N.Y. Acad. Sci.*, 1948, **49**, 161.
[26] Glueckauf, E. *J. Chem. Soc.*, 1947, p. 1302.
[27] Barrow, R. F., Danby, C. J., Davoud, C. M., Hinshelwood, C. H., and Stavely, L. A. K. *J. Chem. Soc.*, 1947, p. 401.
[28] Rathmell, B. L., and Bateman, P. J. *J. Instn. H. & V. Engineers*, 1952, **19**, No. 198, 471.
[29] Miller, A. W., and Roberts, C. W. *Industrial Chemist*, March 1958.
[30] Heertjes, P. M., de Boer, J. H., and van Dorsser, A. H. de H. *Chem. Eng. Sci.*, 1953, **2**, 97.

[45] Hsu, C. T., and Molstad, H. C. *Ind. Eng. Chem.*, 1955, **47**, 1550.
[46] Cox, M. *Trans. Inst. Chem. Engrs.*, 1958, **36**, 29.
[47] Kasten, P. R., and Amundson, N. K. *Ind. Eng. Chem.*, 1950, **42**, 1341.
[48] Kasten, P. R., and Amundson, N. K. *Ind. Eng. Chem.*, 1952, **44**, 1704.
[49] Langmuir, I. *J. Am. Chem. Soc.*, 1918, **40**, 1361.
[50] Zsigmondy, R. *Z. anorg. Chem.*, 1911, **71**, 356.
[51] (a) Brunauer, S., Emmett, P. H., and Teller, E. *J. Am. Chem. Soc.*, 1938, **60**, 309. (b) Brunauer, S., Deeming, L. S., Deeming, W. E., and Teller, E. *J. Am. Chem. Soc.*, 1940, **62**, 1723.
[52] Polanyi, M. *Verh. deut. physik. Ges.*, 1916, **15**, 55.
[53] McGavack, J., and Patrick, W. A. *J. Am. Chem. Soc.*, 1920, **42**, 946.
[54] Foster, A. G. *Trans. Far. Soc.*, 1932, **28**, 645.
[55] Cohan, L. H. *J. Am. Chem. Soc.*, 1938, **60**, 433.
[56] Brunauer, S. "Physical Adsorption of Gases and Vapours", Oxford, 1944.
[57] Proc. 10th Symp. Colston Research Soc. "The Structure and Properties of Porous Materials." Butterworths 1958. (a) Wynne-Jones, W. F. K., p. 35. (b) de Boer, J. H., p. 68. (c) Kiselev, A. V., p. 195. (d) Barrer, R. M., p. 6. (e) Flood, E. A., p. 151 (discussion).
[58] Ross, S. *J. Phys. Chem.*, 1949, **53**, 383.
[59] de Boer, J. H., and Zwikker, C. *Z. Phys. Chem.*, 1929, B3, 407.
[60] Magnus, A. *Z. Phys. Chem.*, 1929, A142, 401.
[61] Freundlich, H. "Colloid and Capillary Chemistry". London, 1926, p. 120.
[62] Second International Congress of Surface Activity. II. Butterworths (1957) (a) Flood, E. A., p. 131. (b) de Boer, J. H., p. 93.
[63] Flood, E. A., and Heyding, R. D. *Can. J. Chem.*, 1954, **32**, 660.
[64] Patrick, W. A., Preston, W. C., and Owens, A. E. *J. Phys. Chem.*, 1925, **29**, 421.
[65] Gregg, S. J. *J. Chem. Soc.*, 1927, p. 1494.
[66] Huber, M. E., Flood, E. A., and Heyding, R. D. *Can. J. Chem.*, 1956, **34**, 1288.
[67] Carman, P. C., and Malherbe, P. le R. *Proc. Roy. Soc.*, 1950, 203A, 165.
[68] Carman, P. C., Raal, F. A. *Proc. Roy. Soc.*, 1951, 209A, 38.
[69] Flood, E. A., Tomlinson, R. H., and Leger, A. E. *Can. J. Chem.*, 1952, **30**, 348.
[70] Gilliland, E. R., Baddour, R. F., and Russell, J. L. *A.I.Ch.E.J.*, 1958, **4**, 90.
[71] La Lande, W. A., McCarter, W. S. W., and Sanborn, J. B. *Ind. Eng. Chem.*, 1944, **36**, 99.
[72] Mantel, L. L. "Adsorption", McGraw-Hill, 1951.
[73] Barrer, R. M. *Brit. Chem. Eng.*, May 1959, p. 267.
[74] Amero, R. C., Moore, J. W., and Capell, R. G. *Chem. Eng. Prog.*, 1947, **43**, 359.
[75] Hougen, O. A., and Dodge, F. W. "The Drying of Gases", Edwards, 1947.
[76] Carter, J. W. *Soc. of Chem. Ind. Proc. Chem. Eng. Group*, 1946, **28**, 98.
[77] Carter, J. W. Inst. of Fuel. Symp. on Drying, October, 1951.
[78] Furnas, C. C. *Tr. Am. Inst. Chem. Engrs.*, 1930, **24**, 142.
[79] Foster, E. G., and Daniels, F. *Ind. Eng. Chem.*, 1951, **43**, 986.
[80] Eagleton, L. C., Ph.D. Dissertation, Yale School of Chem. Engng., 1951.
[81] Carman, P. C. "Flow of Gases Through Porous Media", Butterworths, 1956.
[82] Ministry of Aviation Report (unpublished). Experimental curves reproduced by permission of the Controller, H.M. Stationery Office.
[83] P. Spence & Sons Ltd. Activated alumina catalogue.
[84] Chu, J. C., Kalib, J., and Wetteroth, W. A. *Chem. Eng. Prog.*, 1953, **49**, 141.
[85] Richardson, J. F., and Bakhtiar, A. G. *Trans. Inst. Chem. Engrs.*, 1958, **36**, 283.
[86] Saunders, O. A., and Ford, H. *J. Iron & Steel Inst.*, 1940, **141**, 271.
[87] Löf, G. O. G., and Hawley, R. W. *Ind. Eng. Chem.*, 1948, **40**, 1061.
[88] Calderbank, P. H., and Pogorski, L. *Trans. Inst. Chem. Engr.*, 1957, **35**, 195.
[89] Grossman, L. V. *Trans. Am. Inst. Chem. Engrs.*, 1946, **42**, 535.
[90] Lewiss, W. K., Gilliland, E. R., Chertow, B., and Cadogan, W. P. *Ind. Eng. Chem.*, 1950, **42**, 1319.
[91] Ku, C. C., Huntingdon, R. L., and Reid, L. S. *Trans. Am. Inst. Min. Met. Engrs.*, 1944, **155**, 253.

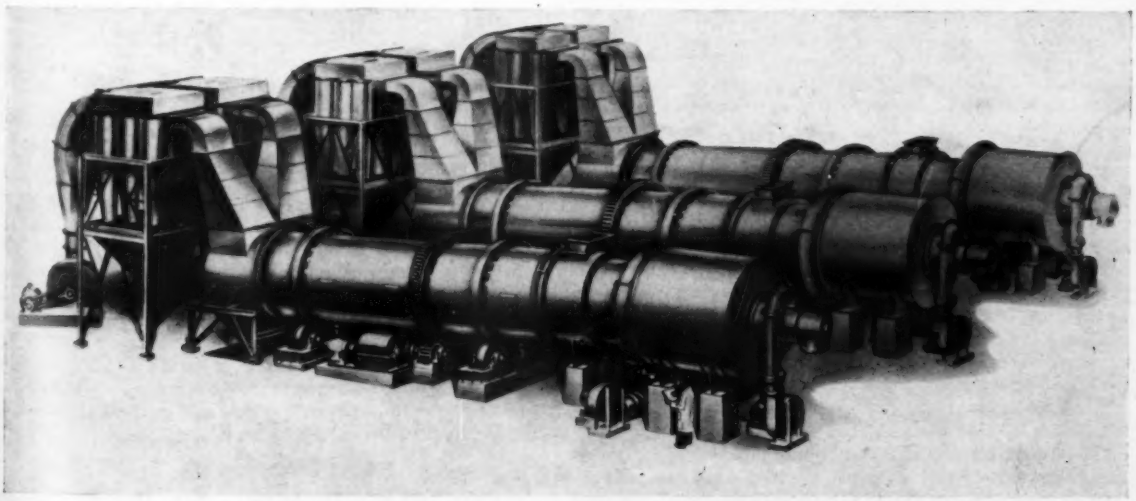
Rotary Driers for Iron Ore Plant

SIX rotary dryers costing approximately £240,000 are to be supplied to Richard Thomas & Baldwins Ltd. for their iron ore drying plant. Each of these machines is 45 ft long by 10 ft in diameter and has a rated capacity of 50 tons per hour when drying from 20% moisture down to 9%. It is believed that these machines will be the most highly instrumented of their kind in this country.

The maximum temperature of dried ore is approximately 200°F with the maximum temperature of exhaust gas, prior to the dust separator being 210°F, and at the exit from the collectors about 200-205°F. The efficiency of the dust collectors is such that with an inlet dust content of 18-20 grains per cubic foot gas, the outlet dust content would be no more than 1 grain per cubic foot. The fan is rated at 37,000 cubic ft per min. approximately 230°F against a resistance of 9 in. W.G.

The dryers are fitted with automatic temperature controls, which will ensure a constant entry and exit gas temperature for a variable feed or feed moisture content. Any variation, therefore, will obviously require an increase or decrease in the heat transfer rate so that to maintain the gas entry and exit temperature, automatic adjustment is made to the gas primary air valves, linkage and dilution air valve. These controls will ensure within limits, a constant predetermined product moisture content. For these variable gas and air rates the exhaust fan is fitted with a damper control. For optimum conditions this fan should be capable of drawing the waste gas and steam through the system, without creating any undue negative pressure at the open feed chute. This control is effected by having the fan damper controlled from pressure points in the vicinity of the feed chute. In addition variable speed control is provided.

The manufacturers of these dryers are Head Wrightson Stockton Forge Ltd.



An artist's impression of a group of iron ore rotary driers supplied by Head Wrightson Stockton Forge to Richard Thomas & Baldwins.

SILICON ALUMINIUM STEELS

OF the 92 natural elements, the majority are very scarce in the earth's crust. In spite of this, we seldom worry about one day running short. Of the elements useful for metallic materials, however, iron, silicon and aluminium are of unlimited supply. New alloys based on these are currently being developed and their properties are not yet widely known.

Silicon steels with up to 4% Si have long been known for their electrical properties. Silicon gives iron oxidation resistance, but also causes loss of ductility. A combination of silicon and aluminium in iron can, however, be found in which ductility is preserved together with oxidation resistance. Such a composition is about 2½% Si and 1% Al. The properties of this steel (or more correctly iron, since it does not have to have any intentionally added carbon but can tolerate up to about 0.3%) have recently been thoroughly studied at the Fulmer Research Institute Ltd. Such an alloy is very oxidation resistant in dry air up to 900°C, so that it can compete with stainless steel in applications like electric furnace radiation baffles or furnace furniture. It is, of course, much cheaper than stainless steel, but does not have the room temperature corrosion resistance or the strength of stainless. Like many other materials, its oxidation resistance falls off in dirty atmospheres like flue gases (see Fig. 1). Its performance in steam atmospheres is lower than in air, but here it behaves far better than mild steel. Another property of this steel is that it is an excellent base for an applied aluminium layer which can be put on by any of the usual processes. The oxidation resistance is also a function of the water vapour content of the atmosphere, as is shown in Fig. 2. A summary of the properties of this material is given for reference in Table I, but fuller data are available.[1]

In exploring the iron-silicon-aluminium system, it is found that brittleness cannot be avoided on raising the silicon content, but the situation is not so hopeless with aluminium additions. Up to 8% aluminium steels can be air cast and worked. For higher aluminium contents either very special technique or vacuum melting and casting are required. For strength at moderate temperatures like 600°C, a 7% aluminium steel would fall between a carbon steel and a chromium molybdenum steel. A steel of this composition has also very good resistance to steam oxidation. Here again we have found that giving a coating of aluminium by dipping in molten aluminium increases the oxidation resistance in air. By this means, aluminium dip-coated alloys of 7% aluminium and 1% silicon have been found capable of standing 1200°C in air for up to 200 hours with hardly any scaling. Small titanium additions to this type of steel further increase its high-temperature strength and this field has been examined at the Ford Motor Co. in America.[2] The hot strength of these aluminium-iron alloys can also be increased by molybdenum additions. As an example, an alloy of 7.2% Al 1% Mo has an ultimate strength of 13.3 tons/sq. in. and 32% elongation at 700°C.

Using vacuum methods, aluminium irons can be made and rolled down with as much as 16% aluminium. This alloy is now known by the American Naval Ordinance Laboratory title of "Alfenol"[3]; when additionally alloyed with 3 to 4% molybdenum, it is called "Thermenol".[4] Alfenol is being considered as a material for magnetic recording tapes, while thermenol has interesting high-temperature strength. In addition, with this high-aluminium alloying, the material is quite rustless and may well have applications because of its corrosion resistance. The drawback to these high-aluminium steels is, of course, the expense of vacuum casting and the relative difficulty in rolling and working. However, enough has been said to make it clear that the system iron-silicon-aluminium—all materials of which the world has plenty—offers many new and interesting materials and a rich field for adventurous exploration.

TABLE I—Data Summary for 2½% Silicon, 1% Aluminium Steel

Oxidation Resistance:
Weight increase after—
1000 hours in air at 900°C .. .. .. 1.3 mg./sq.cm.
1000 hours in air at 700°C .. .. .. 0.6 mg./sq.cm.
Not recommended above 1000°C
300 hours in burnt town's gas at 600°C .. 4.6 mg./sq.cm.
Aluminium coating and 300 hours in burnt town's gas at 700°C .. .. 7.4 mg./sq.cm.
Aluminium coating and 300 hours in burnt town's gas at 900°C .. .. 3.4 mg./sq.cm.
300 hours in steam at 600°C .. .. .. 2.5 mg./sq.cm.

Tensile Strength:
Room temp. Yield point 29.0 tons/sq. in. U.T.S. 37 tons/sq. in. 20% El.
600°C. ,, 12 tons/sq. in. 53% El.

Workability:
Erichsen 8.0.
Axis of bend perpendicular to rolling direction .. ½ t
Axis of bend in the rolling direction .. .. 2½ t

Creep Rate:
0.001068% per hour at 650°C and ¾ tons per sq. in.

Corrosion Resistance:
Similar to mild steel.

Treatment required:
Anneal before working for ½ hour at 900°C, or a few minutes at 1000°C.

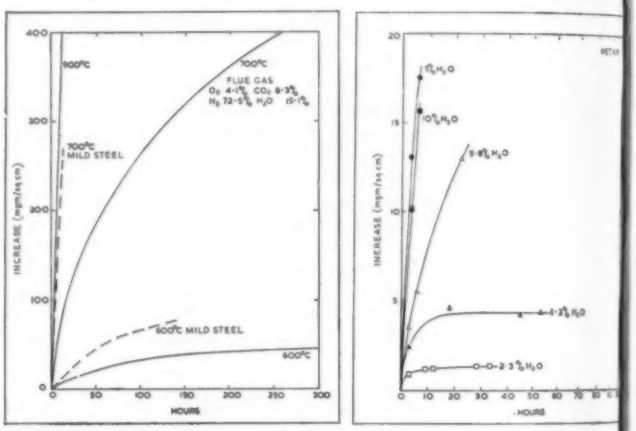


Fig. 1 (left). Scaling curves for 2½% Si 1% Al steel and mild steel in flue gas at various temperatures.
— — — — Mild steel. ———— 2½% Si 1% Al steel.

Fig. 2 (right). The effect of moisture content in volume per cent on the oxidation of a 2½% Si 1% Al steel at 900°C in air.

REFERENCES

[1] Oxidation Resistant Silicon Aluminium Steels. F.R.I. Special Report No. 2.
[2] Lustusson, W., Zackay, V. Z., and Morgan, E. R. A.S.M., 1956, 49.
[3] Nachman, J. F., and Buehlers, W. J. Navord No. 2819, 1954.
[4] Nachman, J. F., and Buehlers, W. J. Navord No. 3700, 1954.

66.045.54

THE RELATIONSHIP BETWEEN DUTY AND SIZE OF A COOLING TOWER

A new method of estimating the enthalpy driving force in mass transfer calculations.

by Professor F. H. H. VALENTIN Ph.D., M.I.Chem.E.*

IN mass transfer processes the transfer duty is usually expressed by the integral

$$\int_{y_2}^{y_1} \frac{(1-y)_M dy}{(1-y)(y-y_i)} = \frac{k_y a z}{G} = H_G z \quad \ldots . (1)$$

for the gas phase.

In the water-air system the gas phase resistance is controlling. If the resistance to heat flow in both the liquid and gas phases is neglected in comparison with the diffusional resistance in the gas phase, the following equation can be derived from Equation (1) above[2]

$$\int_{H_1}^{H_2} \frac{dH}{H^* - H} = \frac{K_Y a z}{G} = H_{OG} z \quad \ldots . (2)$$

A differential material balance in the tower yields:

$$G\,dH = L\,c_p\,d\theta \quad \ldots . (3)$$

If c_p is taken as unity, this becomes:

$$\frac{d\theta}{dH} = \frac{G}{L} \quad \ldots . (4)$$

A combination of Equations (2) and (4) gives:

$$\int_{\theta_1}^{\theta_2} \frac{d\theta}{H^* - H} = \frac{K_Y a z}{L} \quad \ldots . (5)$$

The last expression is known as the Tower Characteristic.[5]

If the effect of evaporation on G and L is neglected, then $\frac{G}{L}$ is a constant for any particular system and Equation (4) becomes:

$$\frac{\triangle\theta}{\triangle H} = \frac{G}{L} \quad \ldots . (6)$$

This is the equation of the operating time.

In order to integrate Equation (5), H and H^* must be expressed in terms of θ.

Now

$$H = H_1 + \frac{G}{L}(\theta - \theta_1) \quad \ldots . (7)$$

Symbols Used

a = specific area of packing, sq. ft/cu. ft tower volume;
c_p = specific heat, Btu/(lb.) (°F);
G = gas rate of flow, lb./(hr) (sq. ft);
H_G = height of gas phase transfer unit, ft;
H_{OG} = height of overall gas phase transfer unit, ft;
H = enthalpy of moist air, Btu/lb. dry air;
H^* = equilibrium enthalpy of air at water interface, Btu/(lb.) dry air;
k_y = gas phase mass transfer coefficient, lb. mols/(hr) (sq. ft) (mole fraction);
K_Y = overall gas phase mass transfer coefficient, lb./(hr) (sq. ft) (lb./lb.);
L = liquid rate of flow, lb./(hr) (sq. ft);
y = mole fraction transferred component in the gas phase;
y_i = mole fraction transferred component in the gas phase at the interface;
y^* = mole fraction transferred component in the gas phase in equilibrium with its concentration in the bulk liquid phase;
z = height of tower, ft;
α, β, γ = constants;
θ = temperature, °F;
Suffix 1 = bottom of tower;
2 = top of tower;
w = wet bulb; and
3 = mean of 1 and 2.

so that equation (5) becomes

$$\int_{\theta_1}^{\theta_2} \frac{d\theta}{H^* - H_1 - \frac{G}{L}(\theta - \theta_1)} = \frac{K_Y a z}{L} \quad \ldots . (8)$$

This can be integrated graphically or numerically using curves or tables of enthalpy versus temperature for moist air. However, in tests or in design work where a large number of performance calculations is required, such methods, if done at all accurately, are tedious and time-consuming.

Functional Relationships

With a suitable functional relationship between H^* and θ, Equation (8) could be integrated algebraically. Three such relationships will be discussed:

* Dr. Valentin *is Professor of Chemical Engineering in The University of Natal, Durban, South Africa.*

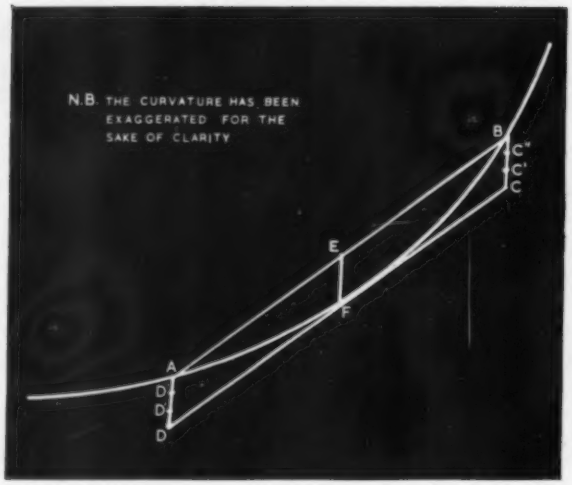


Fig. 1. The geometrical relationships of mean enthalpy correction illustrating the basis of the method described.

Fig. 2. A Power Station showing cooling tower in the background, and electroprecipitators in the foreground. (W. C. Holmes Ltd.).

(*a*) *Linear Relation*

$$H^* = \alpha\theta + \beta \qquad \ldots.(9)$$

This is obviously inaccurate, but can serve for rough calculations. It implies the use of a log mean enthalpy difference $(H^* - H)_{\log\ mean}$. Merkel[5] and workers following him, e.g., Wood and Betts,[8] used the linear approximation and, furthermore, worked with a mean equilibrium enthalpy (H^*_{mean}). This entails the further error of assuming the reciprocal of the mean to be equal to the mean of the reciprocals, but it so happens that the second error partially cancels the first and the various diagrams based on Merkel's approximation give a tolerable accuracy for rough work.

(*b*) *Exponential Relationship*

$$H^* = e^{\alpha\theta+\beta} \qquad \ldots.(10)$$

The first mention of such relationship in the literature is by Fuller.[3] The use of this equation in combination with Equation (8) gives an expression which cannot be integrated algebraically, but is suitable for numerical solution on an electronic computer using Simpson's Rule. Over the range 60-120°F the regression equation is

$$\log_{10} H^* = 0.512 + 0.013\theta \qquad \ldots.(11)$$

This has a standard deviation (on H^*) of 1.9.

The accuracy improves over shorter ranges; e.g., it is 0.9 over the range 65-110°F.

(*c*) *Parabolic Relationship*

$$H = \alpha\theta^2 + \beta\theta + \gamma \qquad \ldots.(12)$$

This type of relationship was first mentioned (by implication) in a paper by Carey and Williamson,[1] although without an indication of its accuracy.

Over the range 60-120°F the regression equation

$$H = 67.9 - 1.9\theta + 0.0187\theta^2 \qquad \ldots.(13)$$

has a standard deviation of 0.7. Over shorter ranges its accuracy increases rapidly; e.g., it is 0.2 over the range 65-110°F.

Deviation of New Methods

If Equation (13) is combined with Equation (8), the resulting expression can be integrated algebraically. However, the function thus obtained is rather clumsy to use and tends to multiply the small errors in Equation (13), particularly if the cooling tower system has a long range and a small approach. It thus appears that the most accurate method for general use would be one which utilised the near-parabolic relationship between H^* and θ without an actual regression equation. This can be done by making use of the fact that the area of any parabola segment is equal to two-thirds the area of the enclosing parallelogram. Thus in Fig. 1, area $ABF = \frac{2}{3}\ ABCD$ $(AE = EB)$.

Now, if the curvature of the equilibrium line is relatively slight, then little error will be introduced if EF, AD and BC are taken as verticals, with DC parallel to AB and passing through F (where F is on the equilibrium curve and on the vertical through E). This means that ABF is nearly equal to $ABC'D'$, where $\frac{1}{2}EF = AD' = BC'$. Furthermore, $ABC'D'$ will be equal to ABC'' or to ABD'', where $AD'' = BC'' = \frac{1}{2}EF$. This latter arrangement gives greater accuracy, as will be illustrated in the example below.

The new method for cooling tower calculation (and for mass transfer work generally), which it is proposed to call the Corrected Log Mean Enthalpy Method, is based on the above geometrical reasoning and is best illustrated by a worked example:

Data given: $\theta_1 = 80°F$

$\theta_2 = 100°F$

$\theta_w = 60°F$

$\theta_a = 70°F$

$$\frac{L}{G} = -1$$

$H^*_1 = 36.3$ Btu/lb.

(equilibrium enthalpy data are obtained from reference [6] and are on a 32°F base)

$H^*_2 = 64.5$ Btu/lb.

$H_1 = 18.8$ Btu/lb.

(from reference [6])

$H_2 = 38.8$ Btu/lb.

$$H_2 - H_1 = (\theta_2 - \theta_1)\frac{L}{G}$$

$$\theta_3 = \frac{\theta_1 + \theta_2}{2} = 90°F$$

$H^*_3 = 48.6$ Btu./lb.

$$H_3 = \frac{H^*_1 + H^*_3}{2} = 50.4 \text{ Btu./lb.}$$

$\triangle''H_3 = H_3 - H^*_3 = 1.8$ Btu/lb.

$\triangle H_1 = H^*_1 - H_1 = 17.5$

$\triangle H_2 = H^*_2 - H_2 = 25.7$

TABLE I—Comparison of Various Methods for Calculating Tower Characteristics

A. Operating Conditions

	1	2	3	4	5
θ_1	80	77	80	90	90
θ_2	100	87	130	120	110
θ_w	60	75	70	85	60
L/G	1.0	1.0	1.4	1.5	3.0

B. Tower Characteristics

						S.D.
Numerical integration	1.0	4.2	3.7	3.1	1.6	0.0
Graphical integration	1.0	4.3	4.1	3.2	1.6	0.2
Simpson's Rule integration (a)	1.0	4.2	3.9	3.2	1.6	0.1
Wood and Betts' nomograph[6] (b)	1.0	4.5	—	—	1.2	0.4
Pritchard Tables[7] (b)	1.0	—	—	—	1.8	0.2
Carey and Williamson[1] (a)	0.9	4.1	4.2	3.3	1.5	0.3
Log mean enthalpy	0.9	3.9	2.0	2.1	1.3	1.0
Corr. log mean enthalpy	1.0	4.2	3.7	3.0	1.5	0.1

(S.D. = standard deviation. Where the extreme cases are not covered, the standard deviations are not strictly comparable.)

(a) Taken from Fuller[3], who used an exponential (see above) and an electronic calculator.
(a) In the Wood and Betts nomograph and the Pritchard Tables not all cases are covered.

Now deduct $\triangle''H_3$ from the *larger* $\triangle H$ and $\frac{1}{4}\triangle''H_3$ from the smaller $\triangle H$ (deducting the larger correction from the larger difference minimises errors).

$$\triangle'H_1 = 17.5 - 0.6 = 16.9$$
$$\triangle'H_2 = 25.6 - 1.8 = 23.8$$

Corrected mean enthalpy potential

$$\triangle'H_m = \frac{23.8 - 16.9}{2.3 \log_{10}(23.8/16.9)} = 20.1$$

$$\text{Tower Characteristic } \frac{\triangle\theta}{\triangle'H_m} = \frac{20}{20.1} = 1.0$$

Comparison with Other Methods

In Table I, which is an extension of that given in reference [3], the accuracy of various methods for determining the Tower Characteristic is compared for a representative range of cooling tower duties. The wet bulb enthalpy correction is neglected in all cases.

It can be seen that under the wide variety of conditions shown in the table only the corrected log mean enthalpy method and the Simpson's Rule integration yield a consistently high order of accuracy. The former has the very definite advantage of requiring neither an electronic calculating machine nor laborious computations.

It is clear from the derivation of the method that it is a perfectly general one, which can be used in all mass transfer calculations where the equilibrium curve can be approximated by a second-degree polynominal.

REFERENCES

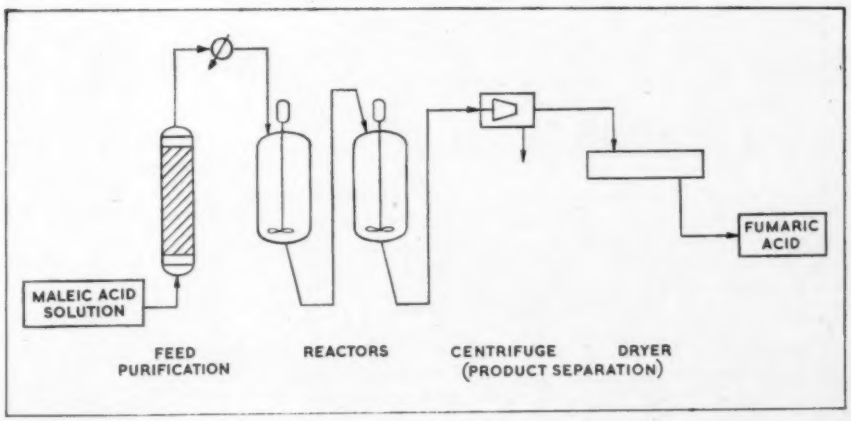
[1] Carey, W. F., and Williamson, G. Y. *Proc. Inst. Mech. Engrs.*, 1950, **163**, 41.
[2] Coulson, J. M., and Richardson, J. F. "Chemical Engineering", Volume I. Pergamon Press, 1954.
[3] Fuller, A. L. *Petroleum Refiner*, 1956, **35**, 211.
[4] McKelvey, K. K., and Brooks, M. "The Industrial Cooling Tower", Elsevier, 1959.
[5] Merkel, F. *V.D.I. Zeitschrift*, 1926, **70**, 123.
[6] Perry, J. H. "Chemical Engineers' Handbook", 3rd edition, McGraw-Hill, 1950, p. 765.
[7] Pritchard, J. F., and Co. "Counterflow Cooling Tower Performance" J. F. Pritchard & Co. of California, Kansas City, 12, Mo., 1957.
[8] Wood, B., and Betts P. *The Engineer*, 1950, **189**, 337, 349.

A New Fumaric Acid Process

A NEW and simple fumaric acid process that offers excellent commercial possibilities for recovering fumaric values from almost any maleic containing feedstock was announced by Scientific Design Company, Inc. of New York. The process can also be used for straight fumaric acid production from prime feedstocks. The new fumaric acid process, the result of work carried out at SD's Research Centre in New Jersey, employs a special catalyst, and is based on moderate isomerisation conditions. Among the important maleic containing feedstocks that can be upgraded are maleic scrubber solution, phthalic scrubber solution, and maleic refiner bottoms. Prime feedstocks include benzene and butenes.

SD's new process is of major importance to maleic or phthalic anhydride producers as a means of utilising waste product streams, and avoiding effluent problems by cleaning up residue streams. The process is a comparatively simple one, involves no difficultly obtainable equipment or chemicals, and results in high yields. The fumaric acid product meets all commercial specifications. An important feature for the small producer or one employing the process for utilising waste streams is the adaptability of the process to plants as small as 2,000,000 lb./year of fumaric acid capacity.

Fumaric acid is related chemically to maleic acid and maleic anhydride and behaves similarly in chemical reactions. It is, however, more stable at elevated temperatures. In polyester resins, the substitution of fumaric acid for maleic acid or maleic anhydride results in greater toughness and hardness, and increased heat resistance. Fumaric acid is also used in other moulding resins, in electrical insulating materials, in elastomers, in plasticisers, in paper sizes, in inks, in household enamels, and in adhesives, to name just some of its many applications.



Simplified flowsheet of SD's Fumaric Acid Process.

66.013 7:657.47

COST OF UTILITIES AND SERVICES

A guide to the cost of electricity, steam, compressed air, refrigeration and other services of importance to the chemical industry*

by R. S. BICKLE, B.A.†

THE questions "What does it cost?" and "Will it pay?" have been in the background of every paper in this symposium. This paper is an attempt to provide some of the answers to the problems of what do the services cost, how much capital is necessary and how can the operating costs of a process be estimated?

A service in a chemical factory is something produced by plant and labour from various materials or supplies which is generally available to any job or process in the works; it is "on tap". If it is supplied at cost, without any additions for distribution, it should be costed as a material and not as a service.

The Cost of Steam

The supply of steam is the most important service in most chemical works. However, the steam supply in factories can vary enormously from, say, a supply at 5 psi heavily loaded with condensate to one at 600 psi or higher with many degrees of superheat. Similarly, boiler plants can range from an old boiler, fully paid off, working to capacity on a cheap waste fuel and with a good water supply, to a new boiler only working at half capacity, with an expensive water treatment plant and with a duplicate boiler as a stand-by. Such extremes can produce steam at costs varying from 5s. per 1000 lb. to 15s. or 20s. per 1000 lb. To make an accurate estimate of the cost of steam for a particular installation, knowledge is necessary of the type of boiler, its size and auxiliaries, its load factor, its water supply and so on. It should be remembered that if it is possible to ascertain all these facts for a given installation, then it is usually easier to find out the cost from someone who already knows the answer.

At today's prices an efficiently run boiler plant in a normal chemical works should provide steam at 8s. 6d. to 10s. per 1000 lb. This covers the fuel costs, water and its treatment, labour, repairs, depreciation and overheads. If the plant is far from the coal fields or other source of fuel, then extra should be allowed to cover the cost of transporting the fuel.

The above price is satisfactory if all the steam is produced at one pressure and all used for heating or all for power generation, and not first for power generation and then using the low-pressure pass-out steam for process heating. Previous papers in this symposium have demonstrated the great economies that can be achieved by combining power raising with the use of pass-out steam for heating.

But in costing steam for different processes it is only fair to distribute the costs correctly to its various users. This allocation of costs can be done in a number of different ways, each unfortunately with a different result. This problem of allocating steam costs is explained well by Oliver Lyle in his "Efficient Use of Steam", and reference should be made to this for details. However, in brief, there are three main ways of allocating costs:

(a) *Total Heat Basis*—where the difference between the heat in the steam entering and leaving each process is used as the basis of the cost.

(b) *Adiabatic Heat Drop*—where it is assumed that all processes occur adiabatically, that is, at the same entropy, and a final state or sink is chosen. Each user is charged with the adiabatic heat drop from its initial steam to the sink and credited with that from its exhaust steam to the sink condition.

(c) *Available Energy*—again a final sink state is chosen. The adiabatic heat drop from the initial steam to the sink condition is again debited to the user, and the adiabatic heat drop from the actual exhaust state, allowing for changes in entropy, to the sink condition is credited to the user.

Oliver Lyle gives a number of worked examples; one is a colliery winding engine exhausting at 15 psi—the exhaust is used to heat the colliery baths. Revising his figures to present-day prices, we have the following different methods of costing:

	Winding Cost	*Baths Costs*
	s. d.	s. d.
1. Total heat basis	1 0	9 0
2. Adiabatic heat drop ...	5 3	4 9
3. Available energy	4 10	5 2
4. Baths direct from boiler ...	10 0	9 0
5. Free waste steam	10 0	—

In practice, having decided on the basis of allocation of the costs, there are always a number of further snags. For example, the process is never completely balanced there is always a reducing valve passing steam or a relief valve blowing off, and these flows are rarely metered.

The Cost of Water

The cost of water is very variable, and so, too, is its quality. The following is a guide for estimating:

(a) *River water*. 1d. to 2d. per 1000 gal., depending mainly on the size of the pumps and the load factor.

* A paper given to the symposium organised by the Graduate and Student Section of the Institution of Chemical Engineers on October 22 and 23, 1959.
† Mr. Bickle is a chemical engineer with the National Coal Board, Hobart House, London, S.W.1.

(b) *Deep wells.* 4d. to 6d. per 1000 gal.

(c) *Domestic water.* The local Water Board will readily give an estimate for any particular industrial use.

For domestic use, a standing charge of about 7% of the net annual value of the property.

For industrial use—1s. 6d. to 2s. per 1000 gal. with reductions for quantity, of the following order:

If over	50,000	gallons	per	quarter	less 6%
„ „	100,000	„	„	„	„ 10%
„ „	1,000,000	„	„	„	„ 16%
„ „	5,000,000	„	„	„	„ 30%

A building contract will be supplied with water at a charge of about 4s. for every £100 of the contract value. For road work a connection to a fire hydrant costs 3s. 6d. per day.

(d) *Cooling Towers*—including the cost of make-up water.

National circulation	2d. to 3½d. per 1000 gal.
Forced draught Induced draught	2½d. to 4d. per 1000 gal.

(e) *Water softening* for boilers of normal pressure cost up to 2s. per 1000 gal. Additives such as sodium hexametaphosphate cost from ½d. to 1d/1000 gal.

(f) River water, coagulated, settled, filtered and chlorinated can cost 6d. per 1000 gal.

The Cost of Electricity

A suitable cost for estimating purposes for electricity is 1½d. per unit.

There are twelve Area Electricity Boards, which all have different industrial tariffs. These tariffs are based on:

(a) demand charge or rental for capacity;

(b) cost of providing and transmitting the electricity.

The demand charge varies with the load factor. A factory operating a single shift for five days a week, and allowing for tea breaks, only has a load factor of 17%. Lower rates are charged for two- and three-shift working, so continuously operating chemical works have some of the best load factors. Special rates are given for high steady loads, such as for aluminium refining, or for the use of furnaces in "off-peak" hours only.

The average cost of electricity to industrial users in 1958/59 varied from 1.134d. to 1.330d. per unit for those areas with coal fields in their area, and from 1.426d. to 1.898d. unit for the non-coal-producing areas. The average size of the demands in the former areas are larger than those in the latter, which account for some of the difference in costs.

The following may serve as a first guide to the industrial tariffs for high-voltage supplies:

(a) Maximum demand below 200 kVA
Standing charges £6 16s. to £8 12s. per installed kVA
Consumption less than 150 kW/month/installed kVA —about 0.8d./unit
Consumption greater than 360 kW/month/installed kVA—about 0.6d./unit
These charges alter by stages to reach

(b) Maximum demand over 3000 kVA (Note: Five Area Boards do not differentiate above demand of 1000 kVA)
Standing charges £5 10s. to £7 10s.
Consumption less than 150 kW/month/installed kVA —0.55 to 0.8d./unit
Consumption greater than 360 kW/month/installed kVA—0.46 to 0.52d./unit

There is also a fuel cost variation addition to cover all changes in the costs of fuel, transport, wages, etc. This addition or reduction is 0.00059d./unit for each penny by which the fuel costs per ton in the year shall be above or below 60s. At present this addition amounts to nearly 0.2d. per unit.

Finally, there is an additional penalty for those accounts charged in kilowatts, if the power factor falls below 0.9 or 0.85; this usually amounts to a few per cent. Of course, if the supply is charged on kVA used, such a penalty is not necessary.

Gas Charges

Again we have twelve Area Gas Boards with different tariffs, and they should be consulted for particular cases. The average price of gas sold to industry in 1958/59 varied from 11.6 to 16.1d. per therm in the coal-producing areas, with an average of 14.1d. In the rest of the country prices varied between 17.8 and 24d. per therm (with exceptional cases up to 32d. per therm), with an average of 18.6d. per therm. The size of the users again affects the differences in costs, as also does the production of gas from coke ovens in some areas.

Small users using less than 1000 therms per quarter would probably pay 16d. per therm in the coal-producing areas, and upwards from 20d. per therm in the rest of the country. The following discounts are indicative only, as the load factor becomes increasingly important with large supplies—

Over	4000	therms/quarter,	discounts	of	10 to 28%
„	10,000	„	„	„	„ 13 to 30%
„	25,000	„	„	„	„ 20 to 30%

Producer Gas

The cost of producer gas was reported by G. O. Bass at a conference organised by the British Coal Utilisation Research Association (*B.C.U.R.A. Quarterly Gazette*, 1957, **32,** 14). For a plant with a capacity of 27,000 therms per day, at 100% load factor the costs are:

4.82d. per therm using coke breeze
6.62d. „ „ „ coal
7.7d. „ „ „ small coke (¾–1 in.)

The cost of the fuel is about 75% of the price per therm. In practice, two plants using coal had costs of 7.87d. and 8.18d. per therm.

A. H. O. Johnson at the same conference gave the costs for a two-stage producer using fuel at 100s. per ton delivered. When producing raw gas at full capacity the cost was 5.41d. per therm, and when producing clean gas at two-thirds capacity five days a week the cost was increased to 7.67d. per therm. The estimated cost per therm to clean producer gas derived from bituminous coals.

Inert Gases

Inert gases cost about 3s. per 1000 cu. ft when supplied at the rate of 3000 cu. ft per hour under a pressure of 100 to 150 psi. For occasional use only, this cost should be greatly increased. Nitrogen on a similar basis costs about 5s. per 1000 cu. ft.

Compressed Air

It has been my experience that the managers and engineers in a factory know the cost of their steam, water, gas and so on, but few have any idea of what their compressed air costs. Their estimates, or guesses, have ranged from ½d. to 21d. per 1000 cu. ft. Highly efficient machines can reduce the price to about 2d., but variable or poor load factors can greatly increase the cost, and suggested costs for estimating purposes are 4d. to 6d. per 1000 cu. ft.

Capital Costs

The capital costs in the succeeding paragraphs are of accuracy sufficient for quick estimating, and reference should be made to Edgeworth Johnstone's paper on quick estimating methods (*Trans. Inst. Chem. Engrs.*, 1954, **32,** 151) for general methods of estimating, scaling up by the two-thirds rule and so forth. His advice should be noted that it is most important that every opportunity be taken to collect cost information, whether of plants, factories or services, always noting details and the date.

Steam Boilers

Frequently the capital costs of plant items are presented as a graph of costs against capacity with a simple single line on it. But this is often misleading, as for example at today's prices the cost of a 1000 lb./hr boiler at 60 psi can vary from £1200 to £2200, the difference being entirely one of quality. So a few prices for individual boilers will be given, allowing for extrapolation by the methods given above

A 2000 lb./hr boiler at 100 psi, delivered excluding chimney and burners, would cost about £2000, and a 4000 lb./hr model from £4000 to £5000. A 25,000 lb./hr boiler at 100 psi can be bought for £10,000 and a 20,000 lb./hr, boiler at 200 psi for £20,000; incidentally, the latter is the largest package boiler that can be bought, weighing some 46 tons. The complete installation of such a boiler, with chimney, fuel storage, etc., can bring the cost up to £50,000 or £70,000.

A couple of Lancashire boilers of 10,000 lb./hr each complete with buildings, chimney, but no fuel storage, will cost £40,000 to £50,000.

Edgeworth Johnstone in his paper stated that a vertical fire tube boiler cost 15s. per lb. of steam per hr in 1949 (delivered but not erected); this at today's prices is 27s. per lb. per hr. Similarly, a water tube boiler is now 45s. It will be seen that the prices quoted above vary from 16s. to 44s.

The cost of a boiler increases by 1½ to 2% for each psi rise, and boilers operating at 1200 to 1500 psi cost £12 to £15 per lb. per hr for the range 2000 to 5000 lb./hr.

A 50,000 lb./hr boiler at 400 to 600 psi costs £150,000 to £170,000 complete, erected with all auxiliary fans, economisers, etc., but no chimney or grit arrestors. Site clearance, civil engineering, foundations, coal and ash handling, or oil storage, pipework, etc., can add 50 to 100% to the price. This compares with a quotation of £330,000 for a 75,000 lb./hr boiler at 650 psi.

A 1½ million lb./hr boiler at 2400 psi and 1050°F costs £1½ million excluding chimney and dust precipitators. This boiler with a 200-megawatt generator, costing £1¾ million, should generate electricity at 0.3d./unit, the steam being reheated to 1000°F, with an efficiency greater than 35%. Such a boiler takes two years to erect on site.

Electricity Generators

The 50,000 lb./hr boiler at 400/600 psi can operate a 5-megawatt generator, and this, complete with condenser, feed heaters, etc., would cost £105,000. Some costs for back pressure turbines are:

5000 kW	£12.5 per kW
10,000–15,000 kW	£10.3 per kW

Electrical Installations

The cost of the electrical installation in a factory with 1000 to 5000 installed hp, the lighting being included as hp and being 2 to 4% of the total, is between £30 and £40 per installed hp. This is starting with a 3.3-kV supply, and providing transformers to 450–500 volts and to 220–240 volts, switchgear, substations and wiring. This estimate assumes a few large motors of 300 to 400 hp size operating directly on the 3.3-kV supply, and the rest of the motors graded in sizes down to fractional hp motors. The cost should be increased if much spare transformer capacity is installed, or if there are many small motors or much flameproofing. Incidentally, Edgworth Johnstone in his paper quoted costs which are from £40 to £70 per installed hp at today's prices, but he covered a wider range.

If in the above example the transformers are excluded, the cost comes down to £7 to £13 per installed hp. If the size of the installation is reduced to, say, 200–300 hp, the cost can easily rise to £30 per hp without the cost of the transformers. And if the installation consists of small motors of 1½ to 3 hp under completely flameproof conditions, as is found in many chemical plants processing liquids, the installed costs may rise to as much as £100 per hp.

Gas

The cost of a gas supply in a factory is mainly the cost of supplying the pipes, which, on a weight basis, is £400 to £600 per ton installed, cocks, valves, etc., being extra.

Gas Producer

The 27,000 therms per day plant mentioned previously under "Producer Gas" would cost about £250,000, but the full installation, including fuel and ash handling, site work, etc., would increase this to the order of £350,000.

Water

This again is mainly the cost of supplying pumps, pipes, cocks and valves.

Water cooling towers vary greatly in price, depending on the design, duty, materials of construction and so on. This is one case where a number of quotations is desirable. Quotations for widely different duties are a cooling tower for 24,000,000 Btu/hr duty costing £72,000, and a 4000 Btu/hr duty costing £43000.

As a guide for quick estimating, using a different basis a concrete cooling tower for 400,000 gph has been quoted for £70,000 complete, and a 50,000 gph for nearly £20,000. Timber cooling towers are about 30 to 40% cheaper.

Air Compressors

A quick guide for the cost of a compressor for an instrument installation is that the compressor will cost about 5 to 10% of the installed cost of the instruments. Air driers can add another 2 to 5%.

Compressors vary in quality, but, as a first guide, at 100 psi the range 100 cfm to 1000 cfm costs about £2 10s. for each cfm, but when the installation is fitted with a non-flameproof motor, starter, reservoir, relief valves, etc., this cost will rise to about £6 or £7 per installed cfm. Smaller compressors, 20 to 60 cfm, vary from £5 to £3 per installed cfm, and the complete installation from £12 to £8.

The installed hp for a compressor decreases from about ½ hp per cfm for the 20-cfm size to about ¼ hp/cfm for 100-cfm, and approaches ¼ hp/cfm for the 1000-cfm sizes.

Refrigeration

An ammonia–brine refrigeration unit to remove 500,000 Btu/hr at a temperature of −50°C will cost about £60,000 excluding the cost of the brine circuit, and will require a 600-hp motor. To remove 500,000 Btu/hr at 0°C would cost about £15,000 and require a 100-hp motor. The first unit requires 20,000 gph of water and the second 8000 gph.

Estimating Operating Costs

Operating costs of a plant or process, or its "profit and loss" account, are usually estimated for a period which can be a day, week, month (28 days or calendar), 13 weeks or a year. A common method is to cost in periods of 4, 4 and 5 weeks to allow for the 52 weeks in the year. Periodically, a 6-week period or a 53-week year is necessary to keep the accounting period in step with the calendar.

Costs are usually expressd in £'s sterling, shillings or pence and their fraction per unit of feed or product, such as £'s per ton, shillings per gross, pence per gallon, etc.

The following are values which can be used for quick estimating when more accurate ones are not available. Generally an estimate is more in error from items or processes which have been omitted than for those items for which an intelligent guess has been made.

Labour

Process workers in the chemical industry earn between 30s. and 40s. per shift; say an average of 36s. for an intelligent plant operator, and somewhat less for his assistant. "Danger" or "dirty" money is sometimes paid as an extra.

To cover continuous seven-day-a-week shift working, 3½ men on a 48-hour week are necessary to fill one post or 4 men on a 42-hour week. For continuous operation estimates should be based on paying 25 shifts per week per post to allow for payment of double time on Sundays, etc.

Wage charges to cover insurance, holiday pay, concessionary travel, etc., usually amount to 12 to 15% of the wages bill. These charges exclude canteen, etc.

Process Materials

Process materials must, of course, be costed individually, but incidentals or other stores, such as oil, rags and so on, should not be forgotten. These often amount to £1 or £2 per week per section of the factory.

Maintenance

Maintenance can vary between 1 and 10% of the capital cost.

1 to 1½% for buildings, roads, yards, etc.

2 to 3% for most plant with little or no corrosion.

Maintenance costs can often be estimated satisfactorily from the aspect of how much time will be spent, and costing the labour and probable materials.

A craftsman earns 35s. to 45s. per shift and his mate 30s. and 40s. and they often have to work overtime, and if they are backed up by workshops, there can easily be a 100% "on-cost" on their labour.

Supervision

It has been said that supervision averages one-third of the labour costs, but it is frequently more accurate to assess the number of the supervisory staff or the proportion of their time connected with the particular process, then to estimate the salaries of managers, engineers, chemists and foreman and so build up a cost; the British chemical industry averages one qualified man to sixteen workers.

General Expenses and Overheads

These can vary from 40–250% of the labour costs, variations being mainly due to the degree of automation. A general figure for the heavy chemical industry in this country at the present time seems to be about 60% of the labour costs. This is where intelligent estimating or inspired guessing is usually required.

Depreciation

The period over which a chemical plant is depreciated varies widely. Market considerations, expected technical developments and high corrosion rates all affect the depreciation rate. Twenty years is perhaps an average time for an established chemical plant or process. Buildings and civil engineering works are often depreciated over twenty-five to forty years, while motor cars are frequently written off in two to five years.

The methods of charging depreciation and interest vary widely. Considering £100 of capital to be depreciated or written off over twenty years, and neglecting any possible scrap value and with interest being charged at 5%, the following methods can be outlined:

(a) *Straight-line Depreciation*

5% depreciation per year and 5% interest on the total investment. This is £200 over the twenty years.

(b) *Straight-line Depreciation with Interest on Residual Value*

5% depreciation and 5% interest on the residual value will amount to £152 over the twenty years.

(c) *Constant Rate Depreciation*

Depreciating at 10% of the residual value per year and paying 5% interest on the residual value. The remainder of the capital value (£12 approximately) has to be paid off at the end of the twenty-year period. The depreciation and interest payments will amount to £134 over the twenty years.

(d) *Sinking Fund*

This assumes that the depreciation payments are retained within the firm and invested to earn say 3% after tax. These depreciation payments plus their interest earnings have to total £100 after the twenty years. The required payments are calculated from mathematical tables such as those in Inwood's "Tables of Interest and Mortality". Interest, of course, has to be paid on the whole amount. The total payments are £174.4 over twenty years.

If the investment earned 5% after tax, the payments would be reduced to £160.4.

Working Capital

The interest on the capital invested should include that on the working capital; the working capital is the money necessary to finance the day-to-day working of the plant and is, of course, not depreciated, but is recoverable intact at the end of the period of operations.

Working capital is said to vary between 5 and 15% of the annual sales value, or between 10 and 15% of the capital investment. But it is best to calculate it.

On the debit side, there are:

Sales	1 to 1½ months value
Stock of Crude Feed	at cost price
Stock of Intermediate	at estimated value
Stock of Products	at selling prices
Stock of Stores, Spares, etc.	at cost price

On the credit side, there are:

Crude Feed and Process Materials	1 to 1½ months value
Wages	½ month
Holiday Pay	6 months
Salaries	½ month
General Stores, Repair Materials	1½ months
Power, General and Overhead Expenses	1½ months

The difference between the debit and the credit is the working capital required. Frequently the major part is accounted for by the value of the non-moving stocks of crude, intermediates and final products.

Profit and Loss Account

The profit and loss account should show the value of the product and the raw material costs; the difference between these is known as the "Margin".

The "Margin" less the operating costs gives the profit or the loss of the process. This profit (or loss) is determined after paying interest at say 5% on the capital invested, but this 5% can easily be regarded as profit.

The profit expressed as a percentage of the capital invested gives a method of comparing processes.

In conclusion it should be remembered that the above costs are only approximate as guides to estimating; but it is often essential to have relative methods of estimating to differentiate between alternative processes. It is important that every estimate should be carefully labelled "pre-design estimate" or "first approximation estimate", or other approximate wording as an estimate given "off the cuff" can be quoted a few months or even years later as a firm price.

532.542 : 681.121.8 : 66.026

FLOW COEFFICIENT OF PIPE CONSTRICTIONS—PART I

The development of a flow coefficient formula for constrictions used for metering purposes

by T. H. REDDING, M.Sc., F.Inst.P., A.M.I.Mech.E.

THE exact theoretical treatment of flow through closed channels of non-uniform cross-section and, in particular, through channel constrictions used for metering purposes (orifices, nozzles and venturi tubes) is by no means simple. In fact, only in certain cases* is it possible to derive, from purely theoretical considerations, an equation which will relate the wall-pressure drop (over a specified length of channel) to the bulk rate of flow with sufficient accuracy for use in engineering practice. In consequence, almost all data regarding the nature of the flow through such devices—and, in particular, on the wall-pressure-gradient versus the flow-rate characteristic—have been derived by direct experiment or by experiments on models: such model experiments, if designed to satisfy certain conditions laid down as a result of a dimensional analysis of the problem, yield results which permit the prediction of full-scale performance from observations made on the models themselves.

The associated problem of designing pipe-constrictions to satisfy given specifications relating to the (wall) pressure-drop versus flow-rate characteristic again requires reference to experimental data—presented either in graphical form, or in any other form which permits interpolation between the results of the numerous individual experiments concerned. (For metering devices, this information is usually given in graphical form and comprises the subject-matter of several "codes of practice" on pressure inferential metering—as, for example, the International,[1, 2] British,[3] German,[4] American Society of Mechanical Engineers[5] and American Gas Association[6, 7, 8] standards on fluid metering practice.) In this respect the design premises differ markedly from those found in other fields where established laws of nature are, in themselves, sufficient to produce engineering designs (e.g., the performance of almost any given optical system comprising surfaces of discontinuity which are plane or spherical in form can be predicted with extreme accuracy merely by applying the known universal laws of reflection and refraction to each of the surfaces concerned).

Furthermore, for design purposes such information must be presented in the most convenient manner, and once again presentations based on the use of dimensionless parameters (taking the form of dimensionless products of certain powers of the individual variables which specify the system) which emanate from dimensional considerations have the merit of ensuring (a) that all the design parameters are independent of the units used to measure the individual variables which influence the pattern of the flow and (b) that the number of design-parameters is reduced to a minimum —which in the general case of compressible flow is usually four less than the number of individual variables involved. Moreover, since within specified limits there is usually some latitude in the choice of these (dimensionless) parameters, it is often possible to select these so as to take advantage of other experimentally evident factors so as to produce formulæ of algebraic simplicity or formulæ which permit the determination of one specified variable explicitly in terms of the others.

Thus, in the case of incompressible adiabatic flow through a constriction in the body of a pipe of diameter D, dimensional considerations (in the form of applying Buckingham's pi-theorem) lead to the non-dimensional equation:

$$\alpha = \varphi(R, l_1/D, l_2/D \ldots)^* \qquad \ldots.(1)$$

where, referring to Fig. 1,
α and R are, respectively, the (velocity of approach inclusive) flow coefficient of the throttling device and the Reynolds number of the flow in the unconstricted stream, as defined by the equations

$$\alpha = \frac{Q}{A_0}\frac{1}{\sqrt{2p/\gamma}} \qquad \ldots.(2)$$

and

$$R = \frac{VD\gamma}{\eta} \qquad \ldots.(3)$$

in which expressions, and subsequently,

p = the wall pressure drop between upstream and downstream reference sections consequent on establishing a bulk volumetric (upstream) flow-rate, Q;

* For example, in the cases of incompressible flow through a straight pipe of uniform circular cross-section (i.e., zero convergence) and in incompressible flow through an orifice or parallel-throated nozzle installed in the body of a long straight main with pressure tappings in regions of sensibly straight and parallel stream lines—i.e., in the pipe some distance upstream of the constriction and in the throat of a nozzle or in the vena-contracta of an orifice.

* Absolute or mass-system units, in which the dimensional formulæ of all quantities assume the form [(mass)^a × (length)^y × (time)^z] are used throughout this paper.

D = the diameter of the main in which the constriction is installed;

A_0 = minimum normal cross-sectional area of the constriction (i.e., of the throat);

γ and η are, respectively, the upstream values of the fluid density and the viscosity respectively;

V = mean velocity at the upstream reference section (as defined by the relation $V = 4Q/\pi D^2$), and

$l_1, l_2, l_3 \ldots$ are linear dimensions (other than D) which define the geometry of the installation.

Equation (1), which has been given in a previous study,[9] is a particularly convenient choice in so far as it expresses p explicitly in terms of Q, and, by putting $\eta = 0$, can be taken to the limit

$$\alpha = \varphi(l_1/D,\ l_2/D \ldots) \qquad \ldots . (4)$$

an equation which governs flow under conditions where only inertia forces determine the pattern of the flow.

In the analysis which follows, it is proposed to:

(a) derive a constitutional formula for the flow coefficient α—i.e., to express α in terms of the stream parameters which define the pattern of the flow, taking into account the curvature of the stream lines and the hydrodynamic effects thereof; and

(b) determine under what conditions Equation (1), written in the form

$$\alpha = \varphi(a, b, c, \ldots m \ldots n) \qquad \ldots . (5)$$

with $a = R$, $b = l_1/D$, $c = l_2/D \ldots$ can be expressed as

$$\alpha = (k_a, k_b, k_c \ldots k_m \ldots k_n)\,\alpha_0 \qquad \ldots . (6)$$

where α_0 = the flow coefficient of a so-called "standard system", characterised by the fact that $a, b, c \ldots$ have specified values $a_0, b_0, c_0 \ldots$; and

$k_a, k_b, k_c \ldots$ are so-called "operational correction factors",* typically represented by the term k_m, defined as the ratio α_m/α_0—where α_m is the flow coefficient relevant to one only (m say) of the factors $a, b, c \ldots$ differing from the value appropriate to the standard system. (Here we shall assume that we are dealing with relatively minor modifications from the standard system—since it is inconceivable that Equation (6) could hold in the general case in any other circumstances. All the k's are thus assumed to be within the range $0.95 < k < 1.05$.)

The merit of representing the flow equation in the form of Equation (6) (when more than one k-term is involved) is that α can be determined by reference to n curves only, each of which determines the appropriate k as a function of the relevant variable m (say): this is particularly useful to the calculator. It would be wrong to assume that Equation (6) is, *ipso facto*, a necessary consequence of the k's, having values which differ only slightly from unity; or that it is permissible to assume that Equation (6) is established simply because the quantities $(a - a_0)$, $(b - b_0)$, $(c - c_0) \ldots$ are known to be small compared with $a_0, b_0, c_0 \ldots$

Flow Coefficient "α"

The constitutional formula to be discussed for the flow coefficient refers to steady incompressible flow through a pipe constriction in the hydrodynamically general case—i.e., wherein the fluid boundary within the constriction, and upstream and downstream of it, does not necessarily coincide at all points with the contour of the channel walls. Constrictive flow relating to such conditions is shown diagrammatically in Fig. 2, in which are defined additional working parameters thus:

$G = Q\gamma$ = bulk mass rate of flow;

$V = 4Q/\pi D^2$ = (geometrical) bulk pipe velocity;

l_1, l_2 = distances of upstream and downstream pressure taps from a reference channel-section—usually (but not necessarily) taken at the throat of the constriction; and

A_1, A_2 = normal channel sections containing the upstream and downstream pressure taps respectively.

For the general case where curvature of the stream lines is apparent (due either to curvature of the channel walls and/or the incidence of separation) stream surfaces S_1 and S_2 are defined as being surfaces whose normals at every point coincide with the local (i.e., time averaged) direction of flow and whose perimeters coincide with those of the sections A'_1 and A'_2, where these latter areas are those portions of A_1 and A_2 over which the fluid velocity is greater than zero. (Thus, were we dealing with the ideal case of irrotational flow of an inviscous fluid, S_1 and S_2 would coincide with the velocity-potential surfaces. Again, if no separation occurs, A'_1 coincides with A_1, whilst, with no curvative of the stream lines, S_1 coincides with A'_1: similar remarks apply to the sections A_2, A'_2 and S_2.)

Using the same symbols for the identification of a pipe or stream section and the actual area thereof, we have

$$\theta_1 = S_1/A'_1,\ \theta_2 = S_2/A'_2 \qquad \ldots . (7.1) \text{ and } (7.2)$$

$$\mu_1 = A'_1/A_1,\ \mu_2 = A'_2/A_2 \qquad \ldots . (8.1) \text{ and } (8.2)$$

$$j_1 = A_1/A_0,\ j_2 = A_2/A_0 \qquad \ldots . (9.1) \text{ and } (9.2)$$

$$V_1 = \theta_1/S_1,\ V_2 = \theta_2/S_2 \qquad \ldots . (10.1) \text{ and } (10.2)$$

$$\text{so that } \theta_1\mu_1 = S_1/A_1,\ \theta_2\mu_2 = S_2/A_2 \qquad \ldots . (11.1) \text{ and } (11.2)$$

$$\text{and } \frac{S_2}{S_1} = \frac{A_2}{A_1}\frac{\mu_2}{\mu_1}\frac{\theta_2}{\theta_1} = \frac{j_2}{j_1}\frac{\mu_2}{\mu_1}\frac{\theta_2}{\theta_1} \qquad \ldots . (12.1) \text{ and } (12.2)$$

Furthermore, in order to take into account variations of local fluid velocity and pressure over any given stream surface, we introduce so-called "correction" coefficients defined as follows:

$$C_1 = \frac{\int w_1^2 dG}{G}\Big/ V_1^2,\ C_2 = \frac{\int w_2^2 dG}{G}\Big/ V_2^2 \qquad \ldots . (13.1) \text{ and } (13.2)$$

$$Y_1 = \frac{\int (P_1 - p_1) dG}{G}\Big/ (P_1 - P_2),\ Y_2 = \frac{\int (P_2 - p_2) dG}{G}\Big/ (P_1 - P_2) \qquad \ldots . (14.1) \text{ and } (14.2)$$

where w_1 and p_1 are local values of the fluid velocity and pressure over an elemental area ds_1 (of the stream surface S_1) which determines an elemental stream tube carrying a mass throughput dG (see Fig. 2); and P_1 is the wall pressure at the periphery of the pipe section A_1: w_2, p_2 and P_2 have similar meaning for the stream and pipe sections S_2 and A_2 respectively.

The factor C, as defined above, is the so-called kinetic energy correction factor, the value of which, for turbulent flow in closed (ducted) channels is usually not very different from unity. For uniform pipe flow Engel and Davis[10] have evaluated C as a function of the resistance coefficient λ* (and thus of the pipe Renolds number R); the form of the relationship after Engel and Davis, within the range of fully developed turbulent flow, being as shown in Fig. 3. On the other hand, the factor Y in a region of parallel stream lines can safely be assumed equal to zero, but for stream sections

* The name "operational correction factor" is not well chosen—"operational deviation factor" would be much better.

* As defined by the equation $\frac{dP}{dx} = \lambda \frac{1}{D} \gamma \frac{V^2}{2}$ where $\frac{dP}{dx}$ is the pressure gradien at the pipe wall.

carrying curved stream lines it may differ considerably from this value.

Since the integration of w is taken over stream surfaces rather than over pipe sections, the above definitions of C_1 and C_2 differ from those usually given in extended one-dimensional treatments of the subject which attempt to take into account the distribution of velocity over the reference sections. Also, the above discussion introduces terms Y_1 and Y_2 to account for the effect of non-uniform pressure distribution over the stream surfaces. Thus, the concept of general velocity of flow and total pressure retain their simple physical significance, even in regions of rapidly converging stream lines: i.e., the volumetric rate of flow is still given by the integral of the fluid velocity over the reference surface (i.e., the stream surface) and the static pressure at any point is a vector whose direction is perpendicular to the stream surface.

Applying Bernoullis' theorem, as relating to incompressible flow, to the elemental stream tube which passes through points x_1 and x_2 on the upstream and downstream reference (stream) surfaces S_1 and S_2 respectively, we have

$$\frac{w_2^2}{2} - \frac{w_1^2}{2} = \int_{p_2}^{p_1} \frac{1}{\gamma}\, dp - z \qquad \ldots.(15)$$

where z is the irreversible work done (by frictional forces) by virtue of fluid being transferred from x_1 to x_2 via the path of the afore-mentioned stream tube.

Conveniently, equation (15) can be written in the form

$$\int_{(2)} \frac{w_2^2}{2}\frac{dG}{G} - \int_{(1)} \frac{w_1^2}{2}\frac{dG}{G} = \int_{(1)} \frac{1}{\gamma} p_1 \frac{dG}{G} - \int_{(2)} \frac{1}{\gamma} p_2 \frac{dG}{G} - \int z \frac{dG}{G} \qquad \ldots.(16)$$

where the suffixes (1) and (2) imply that integration is taken over the stream surfaces S_1 and S_2 respectively.

Equation (16) can be written in terms of C_1, C_2, Y_1 and Y_2 in the form

$$C_2 \frac{V_2^2}{2} - C_1 \frac{V_1^2}{2} = \frac{1}{\gamma}(P_1 - P_2)\,[1 - (Y_1 - Y_2)] - Z \qquad \ldots.(17)$$

where Z is the total work done by friction per unit mass of fluid in its path from S_1 to S_2.

Furthermore, continuity of mass within the elemental stream tube requires that

$$w_1 ds_1 = w_2 ds_2 = dG/\gamma \qquad (18) \text{ and } (19)$$

which on integration gives

$$V_1 = \frac{S_2}{S_1} V_2 \qquad \ldots.(20)$$

$$G = \gamma S_2 V_2 \qquad \ldots.(21)$$

The flow equation relating G to $(P_1 - P_2)$ is now obtained by eliminating S_2/S_1, S_2, V_1 and V_2 among Equations (20), (12.2), (21), (11.2) and (17) to give

$$G = \frac{\theta_2 \mu_2 A_2}{\left(C_2 - C_1\left(\frac{\mu_2\theta_2 j_2}{\mu_1\theta_1 j_1}\right)^2\right)^{\frac{1}{2}}} \left(2\gamma(P_1 - P_2)[1 - (Y_1 - Y_2)] - 2Z\gamma^2\right)^{\frac{1}{2}} \qquad \ldots.(22)$$

For the purposes of this analysis it is convenient to write Z in the form

$$Z^* = E\frac{V_2^2}{2} \qquad \ldots.(23)$$

and to eliminate V_2, Z and S_2 between Equations (22), (23), (21) and (11.2) to give

* That we choose to express Z in these units (i.e., in terms of $V^2_2/2$) does not necessarily imply any physical significance or specific properties to the new factor E—in particular there is no *ipso facto* reason for assuming that E has the nature of a factor of proportionality.

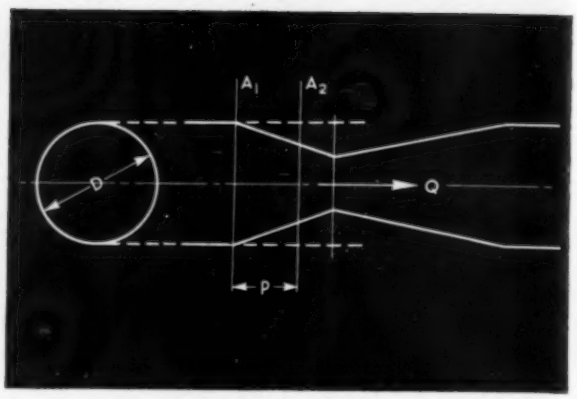


Fig. 1. Definition sketch relating to constrictive flow.

$$G = \frac{\theta_2 \mu_2 A_2}{\left(C_2 - C_1\left(\frac{\mu_2\theta_2 j_2}{\mu_1\theta_1 j_1}\right)^2 + E\right)^{\frac{1}{2}}} \left(2\gamma(P_1 - P_2)[1 - (Y_1 - Y_2)]\right)^{\frac{1}{2}} \qquad \ldots.(24)$$

Equation (24) shows that G is proportional to $(P_1 - P_2)^{\frac{1}{2}}$ only when Y_1 or Y_2 or $(Y_1 - Y_2)$ are independent of $(P_1 - P_2)$. However, in practice, G appears to be proportional to $(P_1 - P_2)^{\frac{1}{2}}$ even where severe upstream curvature of the stream lines and downstream separation, with consequent unsteady conditions at the surface of separation, occur: e.g., close proportionality between G and $(P_1 - P_2)^{\frac{1}{2}}$ is a feature of corner tapped orifice flow—an almost extreme case of both severe stream line curvature before the throttling device, and of contraction within it. (This point, together with others associated with the physical significance of the quantities C_1, C_2, Y_1, Y_2, μ_1, μ_2 and θ_1, θ_2, has been discussed more fully in a previous paper[11] with particular reference to flow through orifices and parallel-throated nozzles.)

Finally, if the flow coefficient is defined (conventionally) by Equation (2) written in the form

$$\alpha = \frac{G}{A_0(2\gamma(P_1 - P_2))^{\frac{1}{2}}} \qquad \ldots.(25)$$

we may eliminate $G/(2\gamma(P_1 - P_2))^{\frac{1}{2}}$ between Equations (24) and (25) to give

$$\alpha = \frac{\theta_2 \mu_2 j_2 (1 - (Y_1 - Y_2))^{\frac{1}{2}}}{\left(C_2 - C_1\left(\frac{\mu_2\theta_2 j_2}{\mu_1\theta_1 j_1}\right)^2 + E\right)^{\frac{1}{2}}} \qquad \ldots.(26)$$

This equation has the virtue of revealing the constitution of the flow coefficient (in terms of C_1, C_2; Y_1, Y_2; μ_1, μ_2, θ_1, θ_2 —together with the relevant geometrical factors) when the problem is complicated by the velocity profile, stream line curvature and/or separation at the (reference) sections at whose peripheries the pressure tappings are made. Although it may not be possible, even experimentally, to assign accurate values for the above parameters—which is almost certainly the case where stream line curvature is very severe —Equation (26) may indicate the trend of the change in the flow coefficient consequent upon change in one or more of the factors which influence the flow pattern.* It is interest-

* However, it should be noted that Equation (26) only holds for a channel linked by path lines which are themselves identical with the stream lines—a necessary consequence of steady conditions prevailing throughout the fluid stream. If, as is the case for orifice flow at high Reynolds numbers, the production of eddies at the surface of separation gives rise to zones of unsteady flow, any precise one-dimensional treatment has to reject all flow paths which are sufficiently near the walls to result in their possibly becoming eddies ejected from the main stream. Equation (24) then takes the form $KG = \theta_2\mu_2 A_2[C_2 - C_1(\mu_2\theta_2 j_2/\mu_1\theta_1 j_1)^2 + E]^{-\frac{1}{2}}[2\gamma(K'P_1 - K''P_2)(1 - (Y_1 - Y_2))]^{\frac{1}{2}}$ where $G(1 - K)$ is the mass throughput associated with unsteady flow paths and K' and K'' are factors introduced to take into account the pressure drop (due to eddying) between the channel walls and the main (steady) fluid stream.

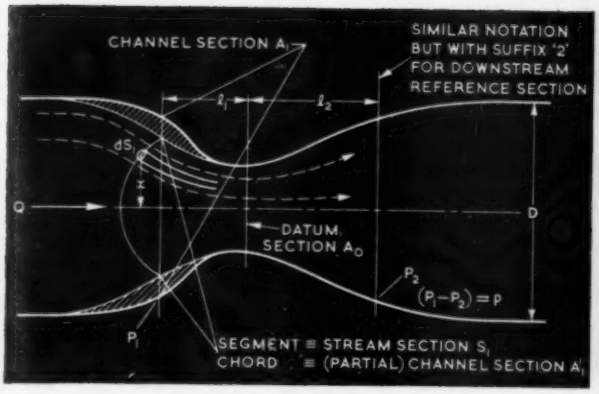


Fig. 2. Definition sketch relating to curvature of stream lines in constrictive flow.

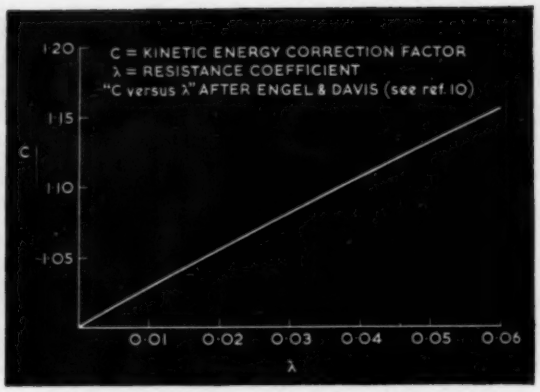


Fig. 3. Flow in smooth pipes: characteristic "C versus λ".

teresting to note that the conventional formula for constrictive flow—extended to include the effects of velocity profile and stream line curvature—follows immediately from Equation (26) if, following convention, we express the contraction at downstream pressure tap in terms of the area of the throat: thus, if we write

$$\Psi_2 = A'_2/A_0 \qquad \ldots.(27)$$

we can eliminate A'_2 and A_0 between Equations (27), (8.2) and (9.2) to give

$$\Psi_2 = j_2\mu_2 \qquad \ldots.(28)$$

and thus, from (26),

$$\alpha = \frac{\theta_2\Psi_2(1-(Y_1-Y_2))^{\frac{1}{2}}}{\left(C_2 - C_1\left(\frac{\theta_2\Psi_2}{\theta_1\mu_1 j_1}\right)^2 + E\right)^{\frac{1}{2}}} \qquad \ldots.(29)$$

If now the upstream pressure tap is taken at a point before the constriction where the main has its full (non-constricted) diameter D, we have

$j_1 = A_1/A_0 = 1/m$ say, where $m = A_0/A_1$ .... (9.1) and (30)

so giving

$$\alpha = \frac{\theta_2\Psi_2(1-(Y_1-Y_2))^{\frac{1}{2}}}{\left(C_2 - C_1\left(\frac{\theta_2}{\theta_1\mu_1}\Psi_2 m\right)^2 + E\right)^{\frac{1}{2}}} \qquad \ldots.(31)$$

which with the conventional assumption that $Y_1 \simeq Y_2 \simeq 0$ and $\theta_1 \simeq \theta_2 \simeq \mu_1 \simeq C_2 \simeq 1$
reduces to

$$\alpha = \frac{\Psi_2}{(1-C_1\Psi_2^2m^2+E)^{\frac{1}{2}}} \qquad \ldots.(31.1)$$

However, Equation (26) is preferable to Equation (29), since it has the advantage of taking into account separately (through the terms j_1 and j_2) the geometrical and physical factors associated with a change of position of the upstream and downstream pressure taps: moreover, Equation (26) can be expressed in a more compact form,

viz.: $$\alpha = \frac{X}{(C_2 - Z)^{\frac{1}{2}}} \qquad \ldots.(32)$$

where $$X = \theta_2\mu_2 j_2(1-(Y_1-Y_2))^{\frac{1}{2}} \qquad \ldots.(33)$$

and $$Z = C_1\left(\frac{\mu_2}{\mu_1}\cdot\frac{\theta_2}{\theta_1}\cdot\frac{j_2}{j_1}\right)^2 - E \qquad \ldots.(34)$$

Operational Correction Factors k_a, k_b, k_c

In deriving expressions for these coefficients we consider first the case where only two terms are involved—k_a and k_c say. Thus, let α_0, X_0 and Z_0 represent the values of α, X and Z respectively in the standard system and α_a, X_a and Z_a represent values of these quantities in an installation which differs from the standard system only in so far that one variable, for example "a", differs from its value in the standard case. Then:

$$\alpha_0 = \frac{X_0}{((C_2)_0 - Z_0)^{\frac{1}{2}}} \qquad \ldots.(35)$$

and $$\alpha_a = \frac{X_a}{((C_2)_0 - Z_a)^{\frac{1}{2}}} \qquad \ldots.(36)$$

so that $$k_a = \frac{\alpha_a}{\alpha_0} = \frac{X_a}{X_0}\left(\frac{(C_2)_0 - Z_0}{(C_2)_a - Z_a}\right)^{\frac{1}{2}} \qquad \ldots.(37)$$

Assuming now, as is often the case, that $(C_2)_0 \simeq (C_2)_a \simeq 1$ and that Z_0 and Z_a are small compared with unity—so permitting the identity $(1 - Z_0)/(1 - Z_a) = 1 - Z_0 + Z_a$—we may write

$$k_a = \frac{X_a}{X_0}(1 - Z_0 + Z_a)^{\frac{1}{2}} \qquad \ldots.(38)$$

the required analytical expression for the correction factor k_a. Similarly, if in another system, the variable "b", say, is the only factor which differs in value from that of the standard installation, we may write:

$$k_b = \frac{X_b}{X_0}(1 - Z_0 + Z_b)^{\frac{1}{2}} \qquad \ldots.(39)$$

If now α_{ab}, X_{ab}, $(C_2)_{ab}$ and Z_{ab} are the values of α, X, C_2 and Z respectively in a system which differs from the standard case in so far that both the factors "a" and "b" assume values which differ from their respective values in the standard system, we have, in the case where $(C_2)_{ab} \simeq 1$, the relations

$$\alpha_{ab} = \frac{X_{ab}}{(C_2)_{ab} - Z_{ab}^{\frac{1}{2}}} \qquad \ldots.(40)$$

and $$k_{ab} = \frac{X_{ab}}{X_0}(1 - Z_0 + Z_{ab}^{\frac{1}{2}}) \qquad \ldots.(41)$$

so that

$$\frac{k_{ab}}{k_a k_b} = \frac{\frac{X_{ab}}{X_0}[1 + (Z_{ab} - Z_0)]^{\frac{1}{2}}}{\frac{X_a X_b}{X_0^2}[1 + (Z_a - Z_0)]^{\frac{1}{2}}[1 + (Z_b - Z_0)]^{\frac{1}{2}}} \qquad \ldots.(42)$$

If, further, $((Z_a - Z_0)(Z_b - Z_0))$ is assumed small compared with unity and with $X_0 \simeq X_a \simeq X_b \simeq X_{ab}$—a condition which usually prevails with non-standard constrictive metering devices (where the immediate downstream flow pattern is tolerably independent of changes in upstream conditions or in more-distant down stream conditions)—we may write Equation (42) as

$$\frac{k_{ab}}{k_a k_b} = \{1 + (Z_{ab} - Z_0) - [(Z_a - Z_0) + (Z_b - Z_0)]\}^{\frac{1}{2}} \qquad \ldots.(43)$$

Thus the condition for so-called linear compounding of k_a and k_b — i.e., that we may write $k_{ab} = k_a k_b$ — is simply that

$$(Z_a - Z_0) + (Z_b - Z_0) = (Z_{ab} - Z_0) \quad \ldots . (44)$$

Whilst it would, indeed, be extremely unlikely to find this relation satisfied generally, it is not inconceivable that, in some cases, we may find the relation is satisfied because either $(Z_{ab} - Z_a)$ or $(Z_{ab} - Z_b)$ is independent of a (over the range a_0 to a) and of b (over the range b_0 to b); again, when either of these relations prevail, it is usually because the components of $(Z_{ab} - Z_a)$ and $(Z_{ab} - Z_b)$* are themselves independent of a and b respectively.

On the other hand, if, in practice, Equation (44) is not satisfied, so that instead of (44) we write

$$\beta[(Z_a - Z_0) + (Z_b - Z_0)] = Z_{ab} - Z_0 \quad \ldots . (45)$$

it follows—from Equations (43) and (45)—that

$$\frac{k_{ab}}{k_a k_b} = \{1 + (\beta - 1)[(Z_a - Z_0) + (Z_b - Z_0)]\}^{\frac{1}{\beta}} \quad \ldots . (46)$$

The above results can clearly be extended to cover the case of any number, n say, of operational variables provided $(Z_{abc\ldots m\ldots n} - Z_0)$ and all the terms like $(Z_m - Z_0)$ are small compared with unity. Accordingly, in the general case (which, in practice, rarely includes more than four terms) we have

$$\frac{k_{abc\ldots m\ldots n}}{k_a k_b k_c \ldots k_m \ldots k_n} \{1 + (Z_{a\ldots b\ldots c\ldots m\ldots n} - Z_0) - \Sigma(Z_m - Z_0)\}^{\frac{1}{\beta}} \quad \ldots . (47)$$

so that linear compounding of the operational correction factors is permissible if

$$\Sigma(Z_m - Z_0) = (Z_{abc\ldots m\ldots n} - Z_0)\dagger \quad \ldots . (48)$$

Again, if, in practice

$$\beta[\Sigma(Z_m - Z_0)] = \Sigma(Z_{abc\ldots m\ldots n} - Z_0) \quad \ldots . (49)$$

it follows that

$$\frac{k_{abc\ldots m\ldots n}}{k_a k_b k_c \ldots k_m \ldots k_n} = \{1 + (\beta - 1)\Sigma(Z_m - Z_0)\}^{\frac{1}{\beta}} \ldots . (50)$$

The above arguments, to some degree, refer to particularly simple cases in which the flow stream is steady throughout, where the X's are approximately equal and where all the difference terms—like $(Z_m - Z_0)$—are small compared with unity.* Even so, the argument is sufficient to demonstrate the essentially incorrect—but nevertheless quite common—assumption that, simply because the terms like $(Z_m - Z_0)$ are small, $k_{abc\ldots m\ldots n}$ is necessarily the same as the product $k_a k_b k_c \ldots k_m \ldots k_n$—an assumption which overlooks the fact that the factor β might very well be other than unity. Thus, for example, if we are concerned with three variables where, with $Z_0 = 0.2$, $Z_a - Z_0 = Z_b - Z_0 = Z_c - Z_0 = Z_0/50$ and $\beta = 3$ evaluation of Equation (50) gives $k_{abc}/k_a k_b k_c = 1.012$: whilst with $\beta = 3$, $Z_0 = 0.2$ and $Z_a - Z_0 = Z_b - Z_0 = Z_c - Z_0 = Z_0/20$, $k_{abc}/k_a k_b k_c = 1.03$. If therefore, in these examples we had assumed that $k_{abc} = k_a k_b k_c$ errors of 1% and 3% would have been involved in the calculation of G in terms of p—errors which could be inadmissible in the case of flow through a constriction used for metering purposes. With larger values of Z_0 the error due to the assumption that the k's may be obtained from their product tends to increase even more sharply and Equation (50) —which assumes that Z_0 is small compared with unity—gives an underestimate of the value $k_{abc\ldots m\ldots n}/k_a k_b k_c \ldots k_m k_n$; thus, for example, with $Z_0 = 0.5$, $\beta = 3$ and $Z_a - Z_0 = Z_b - Z_0 = Z_c - Z_0 = Z_0/50$ the exact evaluation of $k_{abc}/k_a k_b k_c$ is 1.071. Similarly, where two variables are concerned it can be shown that it is inadequate to assume that $k_{ab} = k_a k_b$ simply because k_a is small compared with k_b or vice versa.

* Thus, writing Equation (34) in the form $Z = \zeta - E$, where $\zeta = C_1(\mu_2\theta_2 j_2)^2/(\mu_1\theta_1 j_1)^2$, we satisfy the condition $Z_{ab} - Z_0 = (Z_a - Z_a) + (Z_b - Z_0)$ if (a) $\zeta_{ab} - \zeta_0 = (\zeta_a - \zeta_0) + (\zeta_b - \zeta_0)$ and (b) $E_{ab} - E_0 = (E_a - E_0) + (E_b - E_0)$: in many cases which occur in practice we find that, as a first approximation, $(E_a - E_0) = (E_b - E_0) = 0$.

† This result is, in fact, a particular case of a more general relation, viz.: $k_{ABC\ldots M\ldots N} = k_A k_B k_C \ldots k_M \ldots k_N$ providing $\Sigma(Z_M - Z_0) = Z_{ABC\ldots M\ldots N} - Z_0$) where, typically, $K_M = \alpha_M/\alpha_0$ with α_M representing the flow coefficient of a modification of the standard system which involves non-standard values of a *number* of the operational variables $a, b, c \ldots n$.

Again, if condition (48) is satisfied, it is usually (although not necessarily) because conditions are such that a change in the value of Z) in the general case when $Z = Z_{abc\ldots m\ldots n}$) due to a change in value of any one operational variable, m say, is independent of the value of the rest — i.e., of $a, b, c \ldots n$.

REFERENCES

1. Technical Committee I.S.A. 30, *I.S.A. Bulletin 9* ("Rules for measuring the flow of fluids by means of nozzles and orifice plates", Arts. 1, 2, 3, 4 and 5—preliminary recommendations). 1st edition. Basle (Switzerland): International Federation of the National Standardising Associations. (1935). (N.B.: I.S.A. = International Federation of the National Standardising Associations—an organisation which preceded the present International Organisation for Standardisation (I.S.O.).)
2. Technical Committee I.S.A. 30, *I.S.A. Bulletin 12* ("Rules for measuring the flow of fluids by means of nozzles and orifice plates", Arts. 6 and 7—preliminary recommendations). 1st edition. Basle (Switzerland): International Federation of the National Standardising Associations (1936).
3. B.S.I. Technical Committee on Temperature Measurement, Gas Flow and Pressure Measurement, *B.S.1042: 1943.* ("British standard code on flow measurement.") 1st edition. London: British Standards Institution (1943).
4. Stromungsmesserausschuss des Vereines Deutscher Ingenieure. *D.I.N 1952.* ("Regeln für die Durchflussmessung mit genormten Düsen, Blenden und Venturidüsen".) 6th edition. Berlin: V.D.I. Verlag (1948).
5. A.S.M.E. Special Research Committee on Fluid Meters, *Report of A.S.M.E. Special Research Committee on Fluid Meters. Part 1.* ("Fluid meters—their theory and application"). 4th edition. New York: American Society of Mechanical Engineers (1937).
6. A.G.A. Gas Measurement Committee, *Gas Measurement Committee Report No. 1.* 1st edition. New York: American Gas Association (1930).
7. A.G.A. Gas Measurement Committee, *Gas Measurement Committee Report No. 2.* 1st edition. New York: American Gas Association (1935).
8. A.G.A. Gas Measurement Committee, *Gas Measurement Committee Report No. 2 (1st edition), Appendix A, B, C.* 1st edition. American Gas Association (1935).
9. Redding, T. H., "Definition and Significance of the Flow Coefficient in Accelerated Flow, with Special Reference to Metering Devices", *Journal of Electronics and Control*, vol. 3, 409-38 (1957).
10. Engel, F. V. A. E., and Davis, A. J., "Velocity Profiles and Flow of Fluids through a Contracted Pipeline", *The Engineer*, vol. 166, 720-1 (1938).
11. Redding, T. H., "Minor Losses in Metering Nozzles", *The Engineer*, vol. 204, 4-7, 41-44, 76-79 (1957).

* One characteristic of such simplified systems (as opposed to the general case wherein the ratio X_{1a}/X_a differs appreciably from unity) is that we cannot multiplicatively compound correction factors with respect to different "standard" systems unless these systems themselves have a common value of Z: i.e., in order to be able to write $\alpha = k_a k_{1a} = k'_a k'_{1a}$ we must have $Z_0 = Z_0'$ —a result which follows at once from equation (44). However, this condition $(Z_0 = Z_0')$ does not imply that the two standard systems are necessarily *physically* identical.

Part-time Course in Chemical Engineering

A part-time day course, of four years' duration, is to commence in the September of this year at the Borough Polytechnic, S.E.1. The minimum entrance qualification for the course, which follows closely the recommendations of the Institution of Chemical Engineers, in their publication "Scheme for Part-Time Course in Chemical Enginering", is an ordinary National Certificate in either Chemistry or Mechanical Engineering. The course, however, is adapted to meet the needs of students with higher qualifications such as graduates who wish to qualify in chemical engineering as a post-graduate subject.

The syllabus is a comprehensive one embracing unit operations, control of process variables and with an emphasis on design. Adequate provisions have been made for practical work during the third and fourth years of the course.

Enrolment dates are Monday or Tuesday, September 19 and 20.

331.86:621.762

THE TRAINING OF POWDER TECHNOLOGISTS IN GREAT BRITAIN

A comprehensive training scheme is proposed to remedy the lack of facilities in this important field

by H. E. ROSE, D.Sc.(Eng.), Ph.D., M.I.Mech.E., M.I.C.E.

THE present-day uses of materials in powdered form are so widespread that it is difficult to name an industry in which such materials do not, at some stage, play a significant part

In view of this widespread use of such materials, and their great economic importance, it is a matter of some surprise to observe that the training of the powder technologist, that is the technologist skilled in the branch of science relating to powdered materials generally, as distinct from the powder metallurgist who deals with metals in powdered form, at present receives no attention in this country, and, furthermore, plans for the introduction of such training do not appear to feature in any scheme, so far revealed to the public, for meeting the increased number of scientific workers demanded by the economy of the country.

The situation in Great Britain, in this respect, compares unfavourably with that existing in several other countries, in which the development of this branch of science is receiving active attention, and schemes for the provision of means for the training of skilled workers in it are being rapidly implemented. It is pertinent to ask, therefore, whether, in view of the critical dependence of the economy of this country upon a prosperous manufacturing industry, failure to develop this field of study, with the wide scope of development which such study could offer, can be justified.

As examples of the importance which is attached to the training of the powder technologist may be quoted the recent inauguration in Germany of Chairs of Powder Technology (Staubtechnik) at Hanover and a Chair of Mechanical Process-technology (Mechanische Verfahrenstechnik), which is largely devoted to the study of subjects within the field of Powder Technology, at Karlsruhe and Munich.

Furthermore, a Chair for Cements, Glass and Ceramics (Mørtel, Glas og Keramik) has been in existence for many years in the Royal Technical University at Copenhagen; a department which under the distinguished direction of Professor A. H. M. Andreasen has produced much notable work relating to the general behaviour and properties of powdered materials.

There is also evidence that facilities for the training of workers in this field are available in Russia; for example, as the following extract from the syllabus of the Faculty of Chemistry of the Moscow State University will show, *all* students taking the course in *General Chemistry* receive comprehensive instruction in this field.

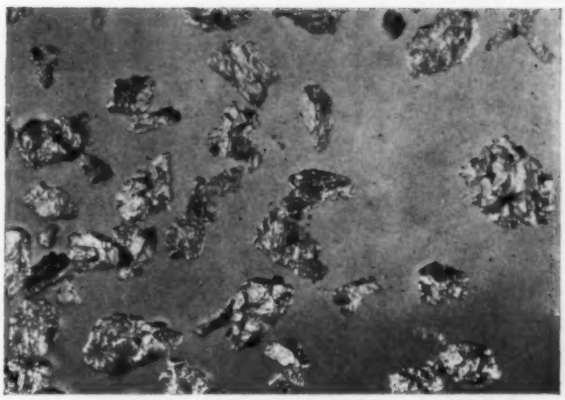


Fig. 1. Niobium particles produced by the hydrogen reduction of the pentachloride in a fluidised bed. A new process described by J. H. Oxley et al.* *(Reproduced by the courtesy of the A.I.Ch.E.).*

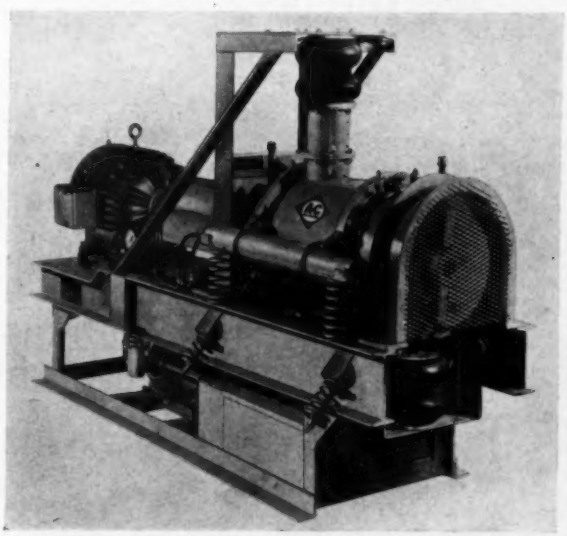


Fig. 2. Medium size industrial vibration mill. (Messrs. Allis-Chalmers Ltd.)

Dr. Rose *is the University Reader in Mechanical Engineering, University of London, King's College.*

* Paper entitled the "Fluidized-bed Process for Production of Niobium", given by J. H. Oxley, G. H. Keeler and I. E. Campbell to the joint A.I.Ch.E.-Mexican Institute of Chemical Engineers Conference, Mexico City, June, 1960.

Technical Chemistry

Section VII. Physico-mechanical Processes

"Crushing and breaking of solids; principles of crushing by impact, pressure, abrasion, cutting, etc.; coarse, medium and fine division; fine and colloidal division; types of crushers and mills; classification of solid materials by dimension, form and specific gravity; nature of aggregation of solid materials; agglomeration and briquetting; mixing in a liquid medium; types of mixers and diffusers; agitation by compressed air; separation of heterogeneous systems; separation of suspensions; filtration and centrifuging; Stokes' law and its importance for determining velocity of precipitation of solids particles; types of sedimentation apparatus; theory of filtration; working principles and types of vacuum filters and presses; types of centrifuge; action of the ultracentrifuge; principles of dry and wet precipitation of solid and liquid particles from gases; dust chambers; cyclone apparatus; scrubbers."

There are also in existence a number of Chairs in subjects which largely overlap with the field under consideration; for example, the Chair of Silica Technology at the Chalmers Institute, Gothenburg, and the Chair of Agricultural Machinery (Landmaschinen) at Munich.

The development of powder technology and the training of powder technologists is also being furthered in other countries by the formation of groups within the professional institutions and similar bodies. Examples are the Granulometry Group in the Swedish Association for Clay Research (Granulometrgruppen inom Svenska Föreningen für Lerforskning), a Powder Technology Group within the Society of Chemical Engineers of Japan, and the Powder Technology Group (Fachausschuss für Staubtechnik) within the Verein Deutscher Ingenieure.

The importance attached to the subject in Western Germany is well exemplified by the activities of the latter group; activities which include the publication of an excellent journal (*Staub*) and other specialist tracts, and the organisation of conferences, which have invariably been well attended (e.g., those at Augsburg, 1954—350; Essen, 1955—650; Hamburg, 1957—350; Bad Godesburg, 1958—550).

Furthermore, the Verein Deutscher Ingenieure, through this group, has rendered technical assistance in the formulation of laws relating to the control of atmospheric pollution; laws which are already in operation in many Länder and which are expected to receive enactment as Federal legislation at an early date. This consulation between the legislators and the technical experts during the drafting of the legislation shows the high esteem in which the group is held, a situation which contrasts rather strongly with the comparative indifference shown by the legislators of this country during the drafting of laws relating to essentially technical problems.

This contrast is not easily explained. Since, however, the subject affects a great many industries, the dispersion of the interest leads to a situation in which, in the absence of a means for bringing together the parties involved, there is no unified voice to state the requirements of the industries concerned.

As a consequence, a wasteful situation prevails in which industries are struggling with problems which are common in other fields, without the knowledge that considerable information relevant to the subject is often available elsewhere.

It is hoped that this paper will stimulate an increased interest in the subject by the industries concerned and so contribute to the development of facilities for the training of workers in this field; also to the general development of this science by the provision of adequate research facilities.

The Scope of Powder Technology

Before entering into details as to courses of study suitable for the powder technologist, it is perhaps desirable to define more precisely the scope of the subject.

In the technical sense a "powder" can perhaps best be defined as a material, consisting of a collection of discrete particles, in which the particles are sufficiently numerous for the properties of the material to be controlled by the statistical behaviour of the totality of the particles, rather than by the properties of the individual particles.

Clearly, in this extended technical sense, the conventional idea of a powder as a material consisting of particles too small for individual observation by the unaided eye is a special case. A dump of coal or metalliferous ore may, technically, be regarded as a powder and, in fact, such materials have all the mathematical properties common to a conventional powder, and so such materials come equally within the field of interest of the powder technologist.

With such a definition in mind, it is clear that the field of

TABLE I

Time-table suitable for a One-year Course for a Post-graduate Diploma in Powder Technology
Time-table for the first two terms. Third term devoted wholly to design, laboratory work, field work and visits to industrial plant.

Hour	Monday	Tuesday	Wednesday	Thursday	Friday
10–11	Industrial uses of powdered materials (Course I) (First term only)	Industrial uses of powdered materials (Course I) (First term only)	Mathematical properties of powders (Course II) (Two terms)	Methods of size determination (Course IV) (Two terms)	Methods of size determination (Course IV) (Two terms)
11–12	Unit processes in powder technology (Course V) (Two terms)	Properties of real powders (Course III) (One term)	Tutorial in above	Tutorials and exercises in above	Atmospheric pollution and air cleaning (Course VII) (One term). Health and other dust hazards (Course VIII) (One term)
12–1	Law relating to industrial dusts (Course VI) (Two terms)	Tutorial in above subjects	Free		Milling technology (Course XII) (Two terms)
	LUNCH PERIOD				
2–3	Surface physics and surface Chemistry (Course IX) (Two terms)	Laboratory work (Two terms)	Free	Statistics (Course X) (Two terms)	Laboratory work
3–4	Laboratory and tutorials in above subjects.			Tutorial in above (Two terms)	
4–5				Design and construction of powder handling plant (Course XI) (One term)	

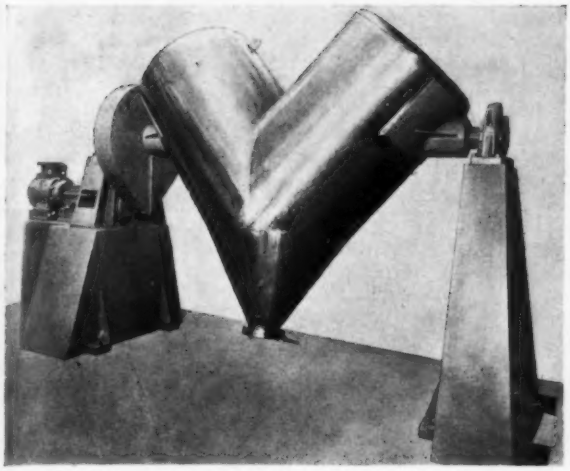


Fig. 3. Large "Y-Cone" mixing machine for powdered materials. (Messrs. Apex Construction Ltd.)

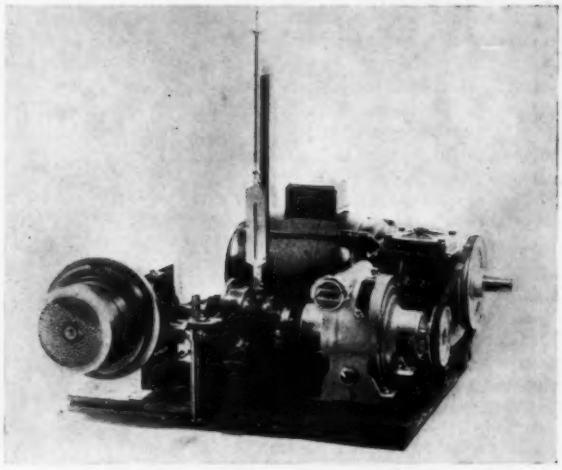


Fig. 4. Small-scale apparatus for research on ball-mills (Author's laboratory).

powder technology is very wide and the following is a representative, though not exhaustive, list of the industries into which the subject enters to a significant extent, together with indications as to the directions in which the subject is of importance within these industries.

Consider first the electrical industry. The processes of powder technology are used in the manufacture of such diverse products as mineral insulated cables and fluorescent light-tubes; high-duty ceramic insulators and the coatings for magnetic recording tape; powdered metal permanent magnets and iron-powder cores for chokes and similar apparatus.

The production of the filaments for lamps and electronic valves also furnish problems in powder technolagy, likewise the manufacture of the heat or electricity insulating or conducting coating used in various types of valves.

In the field of atomic energy there would appear to be great scope for the powder technologist; the problems falling within this subject including the production of fuel from the raw materials and the recovery of spent fuels, the design, construction and operation of filter equipment for the treatment of effluent gases (a need which the escape of radioactive materials during the Windscale mishap appears to emphasise strongly) and research in directions such as the possible production of pelletised fuels, heat transfer between powdered fuels and gases, etc.

The production of pharmaceutical materials is another field in which the knowledge of the technology of powdered materials is invaluable. A great number of drugs are essentially in the form of fine powders and the fundamental processes of milling, mixing, tableting, etc., are extensively used. And clearly the effective control of such processes, and their products demands a knowledge of sampling techniques and processes such as particle size determination.

The manufacture of Portland cement is an interesting example in that it is a very large scale process in which the material is in a technically powdered form throughout the process. Thus, for example, the clay and limestone are removed from the claypit and quarry in the form of a very coarse "powder". This material then is reduced to a slurry which can, from many points of view, be regarded as a dense suspension of fairly fine particles.

A little consideration in this way will show that all the basic processes fall within the field of interest of the powder technologist, these processes being: transport of the chalk or limestone and the clay; washmilling; pumping of the slurry; transport of the clinker through the kilns; heat transfer from the hot gases to the clinker in the kiln and from the clinker to the air on cooling at exit from the kiln; grinding the clinker; size classification of the product; air transport of the product to silos; discharge from silos; packaging or bulk transport; pulverising coal for firing the kilns; electrostatic precipitation for the cleaning of the effluent gases from the kilns and the air in the works; tests for the fineness of the product.

It is perhaps of interest to note that the average running cost of a tube-mill for a cement works is about £40,000 per annum and, thus, even say a 10% reduction in this cost would represent a worth-while saving. Whilst it is difficult to obtain accurate figures, it is the writer's belief that many of these large mills are not being run under optimum conditions and it is known that similar mills grinding apparently identical clinker have throughputs which are in the ratio of about 3:2. Doubtless similar discrepancies arise in other industries and with other processes.

It seems reasonable to believe, therefore, that the supervision of the working of such mills by a powder technologist trained in the theory of the operation of such machines could lead to substantial improvements in the efficiency of operation of the plant. It is also believed that the general conclusion is true for other machines in the cement industry, and is doubtless true for other industries.

As a final example may be quoted the mineral dressing industry. For here the material is often reduced to the form of powder in order that the various separation processes, such as froth flotation, can be effectively applied, and here again milling is an important step in the processes.

It is interesting to notice that the milling operation represents a relatively expensive part of the process and the writer is informed that the past regression in the Canadian metallurgical trade has led to a 50% increase in the number of requests, made to the Research Station of the Canadian Department of Mines, for the prosecution of investigations aimed at improvement in the efficiency of grinding.

Other industries in which powder technology is involved to an appreciable extent are powdered metals; paint and colour; paper; fuel and power; mining; metallurgy; chemical; cermets; ceramics; insecticides; fertilisers; oil refining; woodworking; foodstuffs; baking and confectionery; abrasives; agriculture.

Scope of the Training Required

From the above by no means exhaustive list, it is evident that powder technology covers a wide industrial field and

therefore training in this subject could equally well be related to any one of a number of fields of basic technical education. This view is supported by the fact that it is questionable whether powder technology is a subject sufficiently broad to justify a degree course in its own right and, furthermore, even if such a status were demonstrated, it is doubtful, for the following reason, whether the fullest advantage could be taken of such a course.

This reason is that a training in powder technology is usually required by workers who already hold qualifications in some field of science and it is clearly unrealistic, and from the national point of view uneconomic, to expect workers who already possess a degree, or similar qualification, in, say, engineering, physics, chemistry, pharmacy, medicine, agriculture or mineral dressing to take a further degree course, even if such an additional course were shortened to two years.

Furthermore, as will be seen later, a degree in practically any of the scientific subjects would form a completely satisfactory basis for such a course of training in powder technology. Thus it is probable that the most effective scheme of training would take the form of a post-graduate course in powder technology superimposed upon a degree course in one of the established branches of science.

Such a basis need not necessarily preclude the admission to the post-graduate course of students who do not hold a formal degree, provided that an adequate standard in the underlying sciences has been attained. Furthermore, there would be the possibility of admission, in special cases, of candidates to parts of the course, although, in general, the study of special subjects which are unsupported by study in related fields is not to be recommended.

At this point the question of why the need for the powder technologist cannot be met by the chemical engineer can well be discussed.

The reasons for this are threefold.

(1) A knowledge of powder technology is required by workers holding a wide range of basic qualifications and, as already stated, it is unrealistic to expect such workers to follow an additional lengthy course of study. Furthermore, much of the basic work of a degree course is chemical engineering; for example, thermal processes is of but little value to these workers.

(2) To fill all the posts in which a knowledge of powder technology is desirable would make impossible demands upon the present supply of chemical engineers.

(3) The training of the chemical engineer does not include subjects which are essential to the powder technologist and, furthermore, does not in general take those which are treated to a sufficiently high standard. (As an example of this, it is believed that, theory of grinding and its application to mills is usually but very sketchily treated.)

At this point it should perhaps be emphasised that the provision of training of the type under discussion should not place further demands upon the already limited supply of scientific man-power but would, in fact, offer a training in work which the scientist engaged in industry is already required to do but which, owing to the lack of training in the subject, is often done ineffectually or in a manner which is wasteful of both time and energy.

On the basis of the above discussion it appears to be safe to assume that the greatest part of the student intake would be recruited from the ranks of those physicists, chemists and engineers who proposed to enter some branch of industry, and it is upon this assumption that the following tentative course of instruction is formulated.

This is not to say, however, that the course would not also meet the needs of workers such as pharmaceutical chemists engaged in the manufacturing branches of the pharmaceutical industry, to biologists engaged in research in insecticides and fertilisers, and to metallurgists engaged upon the manufacture of powdered metal products. It is also conceivable that parts of the course, such as those dealing with the statistical basis of sampling or point counting, would be of value to workers with medical qualifications engaged in research in fields such as cytology.

Since a basic premise is that the students would have a degree in one of the established branches of science, it can be accepted that there would be already an adequate background of basic scientific knowledge and so the course could be devoted wholly to the teaching of specialist subjects. Furthermore, since it is clearly undesirable that the training of the technologist should be unduly protracted, and also since it appears that a sound and reasonably comprehensive training in the subject could be given in one year, it is considered that a course of such a length strikes a happy balance between practicability and desirability. A possible time-table of a course of study drawn up on this basis, and on the assumption that two terms of the academic year would be devoted to formal directed studies, whilst the third is devoted to drawing office and laboratory work and to visits to industrial plants, is shown in Table I.

Since the mere title of a course of lectures does not adequately indicate their content, an outline syllabus of each of the courses mentioned in the "time-table" above will now be presented.

Course I: The Industrial Uses of Powdered Materials (20 Lectures)

An introductory course relating to the industrial uses of powdered materials and reviewing topics such as the methods of production, desirable and objectionable characteristics, etc., of powdered metals; cermets, cements; fuels, ceramic slips; foodstuffs; pharmaceutical products; insecticides; fertilisers, etc.

Course II: The Mathematical Properties of Powders (20 Lectures)

A course to cover the theoretical aspects of powder properties such as residue curves; size distribution; "mean" particle size on various bases; elements of crystallography in relationship to particle shape; idealised shapes and shape factors; packing assemblages; theories of comminution and the size distributions deduced therefrom; statistical distributions and their practical limitations.

Course III: The Properties of Real Powders (10 Lectures)

A course complementary to Course II and relating to particle shapes and shape factors; aggregation; flocculation; dispersion; friction in powders; flow properties; distribution of stresses and strains in powder masses; electrification of powders.

Course IV: Methods of Determination of Size and Other Powder Characteristics (40 Lectures and Laboratory)

Sieves; calibration of sieves; sieving; sedimentation; elutriation; adsorption; bulk density, permeability tests; centrifuging; optical methods; microscopy (including phase contrast, dark field, polarised light); spot counting.

Course V: The Unit Processes of Powder Technology (20 Lectures)

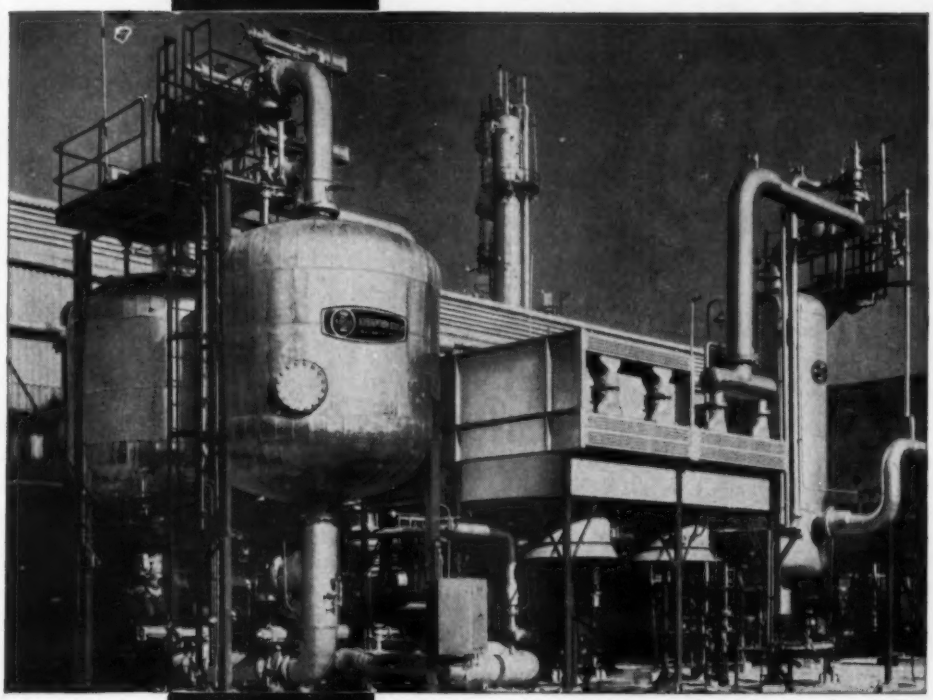
Powder technology dealt with on the basis of a number of fundamental "unit processes" such as precipitation; condensation; size reduction; size separation; type separation; mixing; drying; sintering; briquetting; dispersion; transportation.

Course VI: Laws Relating to Industrial Dusts and Atmospheric and Water Pollution (20 Lectures)

The law relating to industrial diseases; explosions and fire prevention; electrical and other machinery; atmospheric pollution; cleaning of effluent gases; pollution of rivers.

Course VII: Atmospheric Pollution and Air Cleaning (10 Lectures)

Birlec Process Gas Dryers



Birlec power former dryer installation at the Whitegate Refinery of the Irish Refinery Company Limited showing, from left to right, dual adsorber pressure vessels, air-cooled heat exchanger and scrubber tower.

at Whitegate Refinery

In the relatively new power former process for fuel enrichment, dry flue gas is circulated through catalytic reactors during the off-stream cycle. For the Irish Refinery Company Limited at Whitegate, Birlec has built a special dual adsorber dryer for the continuous removal of 240 lbs. of water per hour from the purging circuit. A flow of 18,100 c.f.m. is handled at 100 p.s.i.g. and the dryer maintains an outlet H_2O concentration of 15 p.p.m. (–40°F dewpoint). The plant, which is 20 ft. high and contains 10 tons of desiccant in each pressure vessel, also incorporates a scrubber and a filter for the flue gas and is designed to eliminate the use of cooling water.

An important part of Birlec's service to the petroleum and chemical industries is the design and fabrication of adsorption dryers that guarantee performance in process applications. Additionally, Birlec has wide experience of drying by refrigeration, absorption and compression. During 20 years in the field, Birlec has acquired unrivalled knowledge of costs, capacities, efficiencies, impurities and load fluctuations, and is particularly well equipped for advising on specialist problems with a technical content.

BIRLEC ADSORPTION DRYERS
DRY AIR & GASES

DRYER & GAS PLANT DIVISION OF

AEI-Birlec Limited

ERDINGTON · BIRMINGHAM 24 · Tel. EAST 1544

LONDON · SHEFFIELD · NEWCASTLE-ON-TYNE · GLASGOW · CARDIFF

SM/B 5211

Industries causing pollution; nature of pollution; plant for cleaning effluent gases; plant for air cleaning.

Course VIII: Health and Other Dust Hazards (10 Lectures)

A course of lectures relating to dust hazards and to the means for their minimisation. Health hazards due to special materials (e.g., beryllium); explosion risks; fire risks; incidental risks.

Course IX: Surface Physics and Surface Chemistry Relating to Powders (20 Lectures)

A course of 10 lectures in each of surface physics and surface chemistry to give an understanding of the role of surface structure and properties in relation to aggregation; flocculation; dispersion; flotation; catalysis; adsorption; comminution; wettability; heat of wetting.

Course X: Statistics (20 Lectures)

A course of statistics relating to normal and other population distributions; random processes; sampling and sampling errors; tests for homogeneity of mixing; design of sampling procedures.

Course XI: Design and Construction of Powder Processing Plant (10 Lectures)

A course of lectures relating to the theory underlying powder processing equipment and techniques, such as mills and crushers; separators; mixers; thickeners; conveyors; fluid transporters; bins and silos; sintering plants; pelletising machinery.

Course XII: Mills and Milling Technology (10 Lectures)

A short course of lectures dealing with the theory of mills and milling. Laws of comminution; energy requirements, influence of the mill parameters on rate of grinding; power demand and mill efficiency; mill wear; surging and the breakdown of mill gearing.

Laboratory Work

About fifteen reports on tests carried out in the following fields; particle size measurement; microscopic analysis; sieving; milling; fluid transportation; electrical precipitation; cyclone air cleaner; jig; magnetic separation; motion of particles in fluids; flow from bins and hoppers.

Drawing Office Work

About five designs of plant and apparatus relating to powder technology.

Implementation

There now remains the problem, once it is agreed that such training facilities are desirable, of providing them.

In view of the standard of basic training which is necessary, it would appear that a course such as that described could only reasonably be undertaken in an institution of university standard.

Furthermore, although the diploma awarded on the satisfactory completion of the course might not necessarily be a university award (it could well be a college diploma), the organisation of such teaching in an institution of university status has much to commend it. It would ensure that parallel research in the subject, which is highly desirable if lively and progressive teaching is to be maintained, would be encouraged, since it could be carried out by suitably qualified candidates as university post-graduate research; and so would be open for the award of high degrees.

Although the teaching of mathematics, physics and chemistry in such a course could well be undertaken by the existing relevant departments in an institution of university status, the remainder of the subject has but little in common with those normally taught in the applied science departments of universities or technical colleges, and so the institution of such a course would involve the teaching body concerned in a considerable initial expenditure for equipment for the necessary specialised laboratories.

Furthermore, the recurrent expenditure involved in salaries, for maintenance of the laboratories and for services would also be of a magnitude not lightly accepted.

On the basis of a department to train 12 to 15 post-graduate diploma students, with a similar number carrying out research for higher degrees in the subject, the following estimated figures for the initial and recurrent expenses are believed to be fairly representative:

(1) Initial outlay £15,000-£20,000.

(2) Annual outlay £10,000-£15,000.

From these figures, it is seen that fairly substantial commitments are involved, and although it is improbable that an educational body would allow such considerations to deter it from the provision of novel courses, when such are known to be desirable, no such body can reasonably be expected to undertake expenditure of this magnitude unless the need for the courses and their probable continuity, is clearly demonstrated.

Here, too, it must be remembered that the importance and ramifications of the subject are not well known to those working outside the field and, in consequence, unless the need for such course were made clear by industry itself, there would probably be a reluctance, to initiate such courses.

A further objection which has been raised to academic recognition of powder technology is that the subject is "empirical". A study of the proposed syllabuses, discussed earlier, shows that such a view is fallacious and that the subject is not less founded on rigid scientific principles than are most branches of engineering and is, in fact, probably more so than some. It is probably true to state that any empiricism in the present handling of the subject arises from the lack of means for training in the scientific basis of the subject, and is not inherent in the subject itself.

In view of the foregoing, what would be valuable would be a statement from industry indicating the need for such a course and for a steady supply of powder technologists.

Since the demand for trained powder technologists is spread over a wide range of industries, there exists the difficulty of obtaining such unified action. However, it is possible that some body with an overall interest in many industries, such as the Federation of British Industries, might represent the otherwise unorganised interests.

Any such action on the part of industry would, however, have added weight if backed by action in the form of financial assistance for the provision of the necessary laboratories, for the meeting of recurrent expenditure and for the provision of scholarships, and research fellowships. The point should also be noted that a post-graduate course of the kind described would prolong the training of the student by a year. Since, however, scholarships from the normal sources would not usually be available and financial provision for the maintenance of the student during this extra period would be necessary, this situation could probably best be met by industry granting leave of absence to suitable graduates, to return to take the course or by granting the first year after appointment to industry, on graduation, as leave of absence to follow the course.

It is perhaps not irrelevant to point out that the idea of industry taking an active part in the development of training facilities in various branches of science is not new and such developments have been promoted in two ways.

(1) The direct endowment of a Chair in the subject of of interest.

(2) By industry taking over the full financial responsibility for the newly instituted department for a definite number of years.

It may also be mentioned that, in theory, it is immaterial whether the financial support originates from a single source or from a group of firms working together. In practice, however, the latter arrangement calls for a degree of co-operation which has hitherto been lacking; it is probably this very lack of co-ordination which accounts for the absence of training facilities in this important subject.

COCHRAN

PRESSURE VESSELS WITH A NAME

Pressure vessels by Cochran — built to all standards and specifications in sizes up to 14′ 0″ DIA. and up to 100 tons in weight.

Send us your enquiries — you will find our prices are competitive.

Cochran & Co., Annan Ltd., Annan, Dumfriesshire, Scotland. Annan 111

and at 34, Victoria St., London, S.W.1.

ABBey 4441

621.643.4

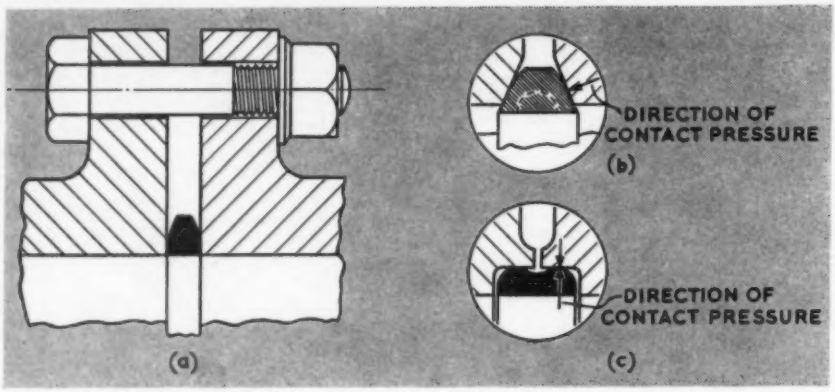


Fig. 1. Self sealing joints.
a. Typical lens ring joint
b. Improved lens ring joint with conical faces
c. Wave ring joint.

SEALING AGAINST PRESSURE AND VACUUM

High Pressure Joints

This paper was presented by Mr. W. R. D. Manning. He first drew attention to the tendency to use higher working pressures. By contrast with steam plant, welded joints for chemical plant are frequently undesirable, and the preference is for joints which can be easily broken and remade.

A pressure joint has two parts, the seal and the coupling. The seal requires a constantly maintained contact pressure and this pressure is reduced if the coupling is insufficiently rigid to withstand deformation, or if creep occurs; the seal then becomes ineffective, which emphasises the point that the seal and coupling must be considered together.

If metal-to-metal joints are considered, then such joints would be theoretically leakproof before the faces actually come into contact with each other. In the case of liquids, the governing factor will be its surface tension and in the case of water at room temperature the critical path width is about 3×10^{-7} in. With gases the dimension would be determined by the size of molecule and by its mean free path, which would mean a clearance several times less than the figure for water. Since the smoothest metal surface produced by normal methods contains irregularities to a 10^{-5}-in. depth, ungasketed metal-to-metal joints are scarcely practical, and the soft gasket used in many joints is to fill up the face irregularities in the softer material, an action produced by pulling the faces together sufficiently tightly to deform the gasket material.

A simple and safe working rule for the bolt load in the bolted-flanged type of joint is given by

$$L \geqq 0.785PD^2$$

where L is the bolt-load, P the working pressure, and D the o.d. of the gasket. This type of joint is used for moderate pressures only, and excessive pressures, by causing the flanges and bolts to deform and thereby transferring the load to the inner rim of the gasket, may burst the latter.

Failures of this kind can be reduced by supporting or trapping the gasket; or, even better, by using a very hard gasket to induce plastic flow in the joint faces. This is the principle of the lens-ring joint where the ring makes a line contact on each side and afterwards indents the soft faces to produce a seal over a very narrow annulus of contact (Fig. 1a).

Such joints have their disadvantages; thus with pressure increase the flange system may deform and reduce the contact pressure at the seating, and high temperatures may cause failure through creep. Such short-comings are reduced considerably in the self-tightening joint which exists in many forms. In such joints, increase in internal pressure automatically increases the contact pressure at the seal. In such a joint, (Fig. 1b), the expansion of the ring with pressure increase, forces it more tightly into the conical joint faces. The effect can be enhanced by giving the ring a concave surface as shown in Fig. 1b. A further development is the wave-ring joint (Fig. 1c), which employs a parallel recess for the ring so that the contact pressure is normal to the pipe axis.

Initially, the ring has to be an interference fit in order to provide the requisite contact pressure, and usually the ring material is softer than the pipe. It is probable that this joint will give a tight seal even when bolt creep occurs; it has the useful property that the sealing forces can be separated from those of the coupling, which is important for very high pressure applications, since end loads have to be considered. It must be noted that the pressure acts over the circle of diameter D_s. With this joint perfect alignment is assured, split couplings can be used, and the pressure in the ring is always greater than the pressure to be sealed.

In another application of a similar principle, a tube is closed by a solid bung of elastic material forced into the bore in front of a steel piston which is supported from behind by a screwed plug (Fig. 2).

When a low pressure is inroduced into the cylinder the contact pressure between the bung and the bore surface due to its initial elastic compression is enough to prevent leakage. If the pressure is then increased, the effect on its free surface is to increase the sealing pressure, and the system remains self-tightening until the walls of the cylinder yield.

A logical development of the last device is the "O" ring in a flanged joint. The "O" ring is retained from behind and compressed at the sides, with the free side exposed to the pressure.

As noted elsewhere, coupling and seal must be con-

Summaries of papers presented to the Conference "Sealing against Pressure and Vacuum", organised by the N.W. Branch of the Institution of Chemical Engineers, on April 26th, 1960.

When did *you* last see a Dutch interior? Never mind! The point is that there's an art to protecting the interiors of tanks. And Ensecote has it. *Any* size of tank. *Any* sort of liquid practically. Ensecote protective linings are easily cleaned and sterilized; completely odourless, tasteless, and economical to install (larger vessels can be lined on the spot). Ensecote protective linings add years to a tank's life.

ENSECOTE *Lithcote* PLASTIC LININGS

For literature and technical advice on linings, and on tank fabrication, write to: NEWTON CHAMBERS & CO. LTD., THORNCLIFFE, SHEFFIELD, ENGLAND

Agents in Belgium, France and Holland: FOURS LECOCQ ET ATELIERS DE TRAZEGNIES REUNIS, S.A., TRAZEGNIES, BELGIUM

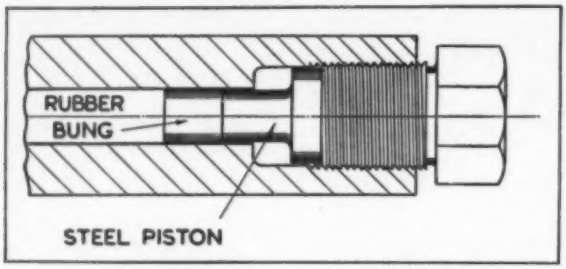


Fig. 2. A self sealing high pressure joint for closing a tube.

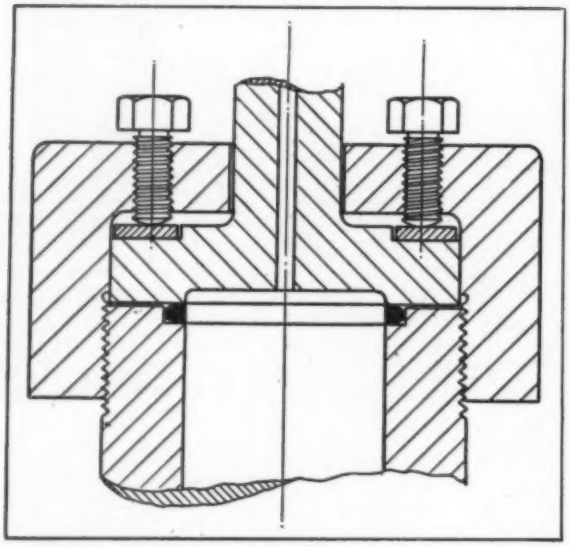


Fig. 3. The main load in this joint is carried by the union nut; final tightening by the set screws (shown by shaded circles).

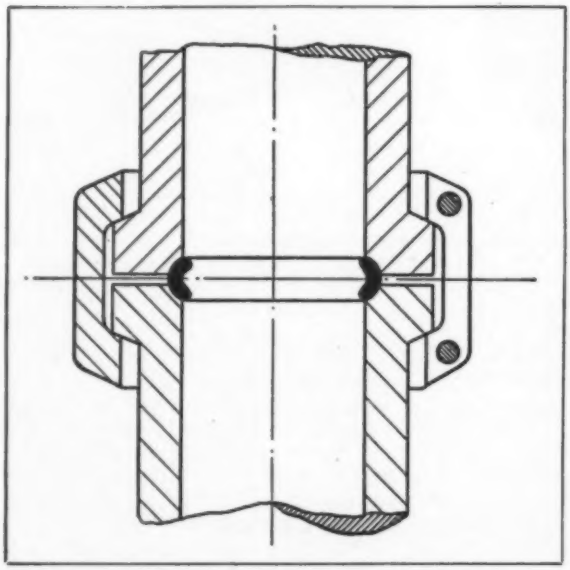


Fig. 4. The Vickers-Anderson system suitable for small axial forces.

sidered together and two types may be distinguished.

One class requires an axial force, in this case a bolt, to supply the contact pressure on the sealing surfaces; another class, for example, the wave ring and the "O" ring, requires no such force. A union connection is usually too large for convenience to use with the first class, but the difficulty can be solved for an end closure by applying a final tightening by a ring of set-screws (Fig. 3).

An arrangement of this kind is desirable for bores greater than 1 in.; for smaller bores a union coupling will suffice.

For small axial forces, as in the self-tightening lens-ring joint, the Vickers-Anderson system may be used (Fig. 4). The coupling consists of three or more sections which, when pulled together, produce an axial compression of the joint ring. The chief assets are the ease of producing a considerable axial force and saving in weight.

Limitations of Temperature and Pressure

Except where pressures are very high, temperature is likely to present the more serious problems, and few non-metallic materials last long at temperatures above 200°C. In such cases metallic seals should be used, but the risk of corrosion of a self-welding must be recognised

High-temperature flanged connection must allow for creep, and the union coupling should not be used except for small sizes, unless wave-ring seals are employed.

Mechanical Seal Applications

"Some experiences in the application of mechanical seals to pumps and stirred pressure vessels" was presented by Mr. V. J. Osola, of the Lankro Chemical Co. He drew attention to the wide range of materials of construction in which mechanical seals can be obtained, which now offer exceptional possibilities of sealing corrosive fluids.

Mechanical seals are now generally available for pressures up to 1500 psig and for temperatures up to 250°C, higher temperatures being permissible through the use of separate cooling systems. For all but the very slow speed applications, the effectiveness of the seal between the rotating and stationary members depends upon the presence of a film of sealing liquid and most failures of shaft seals, other than direct mechanical damage, are caused by the absence of this film.

The questions to be taken into account at the design stage of a shaft sealing arrangement, whether it be for a pump or an agitated vessel, were considered in detail. Thus they should be of the balanced type if the pressure level is high; they should be cooled if there is any likelihood of vapour forming between the sealing face; and recirculation of liquid should be provided for heat dissipation or if dirt and solids are present. Whether the seals are internal or external will depend upon the available space and the operating conditions, and the latter determine also whether single or double seals should be used.

A number of points made by Osola are of importance in the uses of shaft seals for pumps. The installation must satisfy a number of conditions apart from the accurate alignment of shaft and freedom from flexing; it should avoid cavitation which may cause vibration, leading to failure of the seal; if high-melting-point materials are being pumped, then lagged or traced recirculation lines and even a lagged seal-housing may be necessary.

Of the experiences described in detail, one was with a mechanically sealed centrifugal pump for hot water at 30 to 120°C at a pressure of 60 psi.

The seal was not satisfactory, the major reasons being that the axial alignment, although suitable for a packed gland, was not accurate enough for a mechanical seal; also the bearing arrangement permitted shaft deflection.

The failures of shafts of mechanically sealed pumps, also reported by the author, point to the need of a redesign of

Britain's FIRST Newspaper devoted to electronics . . .

. . . is being launched early next month. Its basic aim is to provide an easily readable medium for the rapid circulation of news — scientific, technical, commercial, economic, financial and statistical — relating to the electronic-based industries in the United Kingdom.

This news, however, will be presented and interpreted within the framework of world electronic developments as a whole. From the outset, the approach of ELECTRONICS WEEKLY will be *international*. Not only will it deal authoritatively with national electronic news, but week by week, it will also present news of outstanding developments and trends overseas, as reported by a far-reaching network of carefully chosen technical correspondents in many parts of the world.

We strongly suggest you take advantage of the special pre-publication subscription offer, by completing and mailing the coupon below . . . TODAY.

SPECIAL PRE-PUBLICATION OFFER!

60 post-free issues for only **10/-**

To:
The Circulation Manager, ELECTRONICS WEEKLY
Drury House, Russell Street, London, W.C.2

I accept your introductory subscription offer. Please enter me as a Registered Reader of ELECTRONICS WEEKLY for the first sixty issues. Remittance for **10/-** *is enclosed.*

NAME
(and qualifications if any) _____

POSITION _____ DEPT. _____

COMPANY
or ORGANISATION _____

ADDRESS
(Business or Private as required) _____

_____

FILL IN, THEN POST TODAY! This offer expires Sept. 7, 1960

some pumps when mechanical seals are used, since the absence of the packed gland appears to lessen the support of overhung impeller shaft often used in centrifugal pumps.

Seals for Stirred Pressure Vessels

To avoid failure of mechanical seals used on an agitator shaft, the design employed must restrain upthrust of the agitator and eliminate shaft whip. A successful design is shown in Fig. 5, while a more refined design (Fig. 6) is for a 600-gallon vessel operating at vacuum and at pressures of 250 psig, with temperature well in excess of 100°C. The seal had to be completely heatproof.

A number of features are noteworthy; for example, the

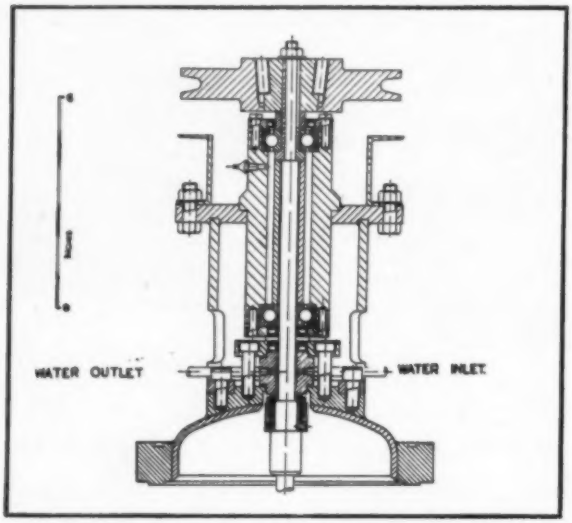


Fig. 5. Prevention of upthrust of agitator and shaft whip is achieved in this design.

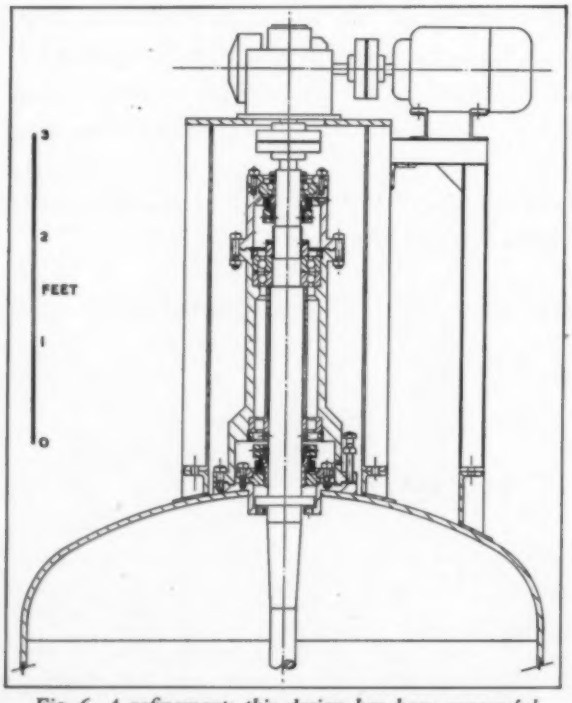


Fig. 6. A refinement; this design has been successful in a 600 g vessel operating at 100°C under pressure or vacuum.

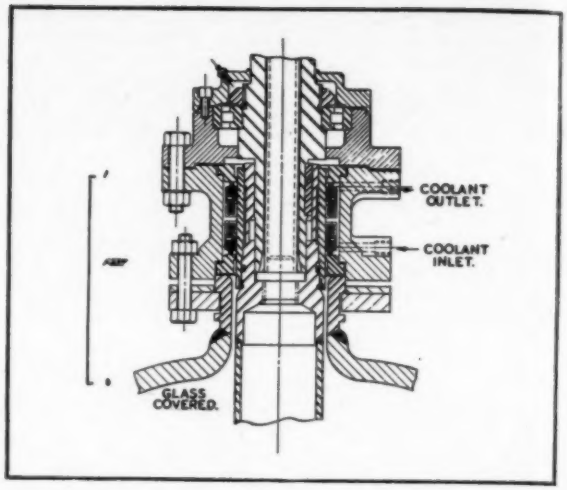


Fig. 7. A successful seal for glass-lined vacuum vessels.

product seal is in the vapour space and the seal assembly is external to the vessel. The bearings are arranged between shaft seals; the coolant is at a higher pressure than the vessel working pressure and the lower seal prevents leakage of coolant into the vessel rather than the escape of vapour.

Apart from the arrangements for making maintenance easy—the shaft can be readily lifted for the purpose—and the fitting of a foot step bearing, the deliberate thinning of the shaft below the lower seal is particularly interesting. This measure ensures that any whip which does occur, despite the steps taken to prevent it, will be confined to the part of the shaft well below the seal. With this type it is essential that the stationary part seats correctly in its housing.

Important Design Features

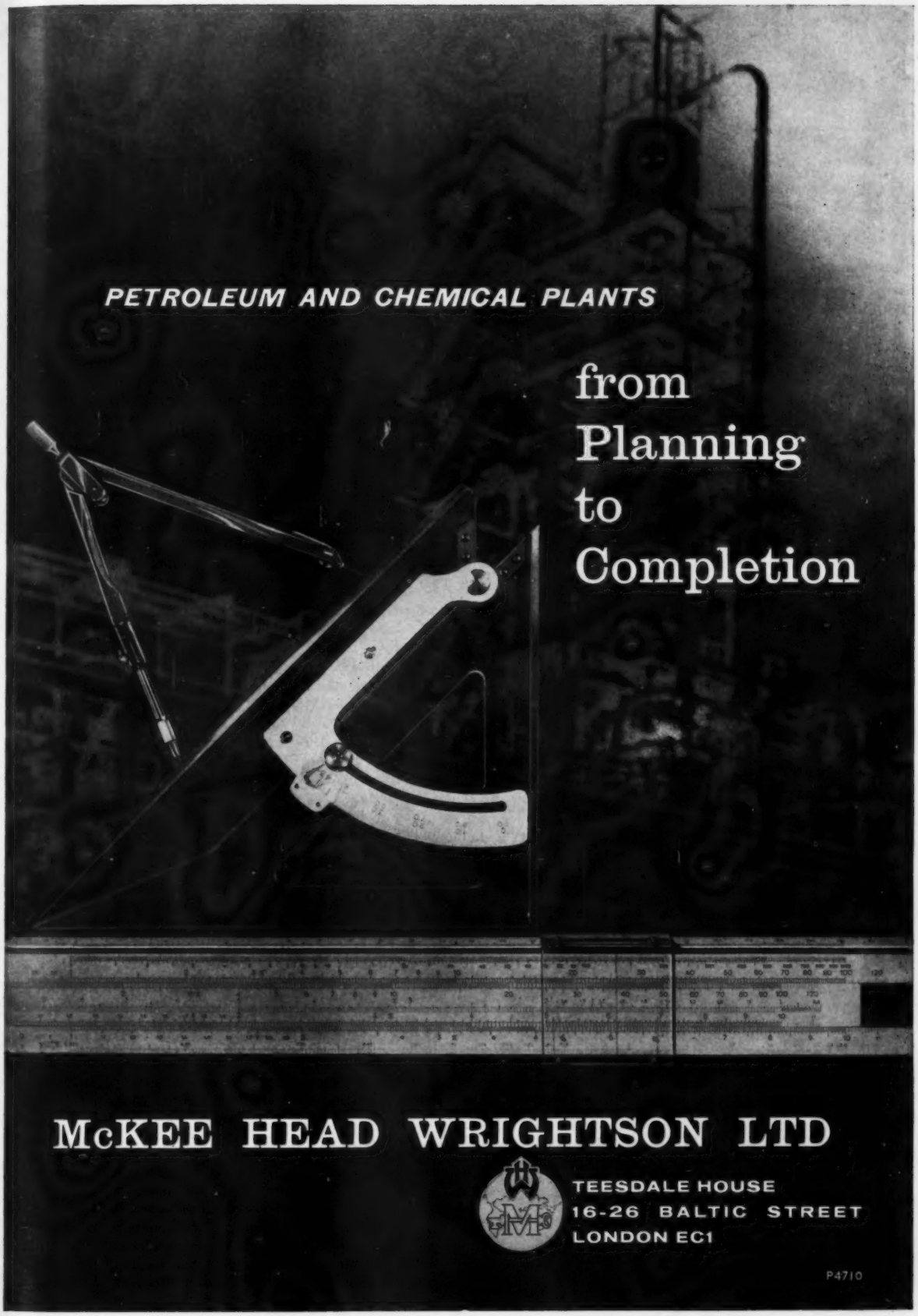
A number of points should be observed in the design of a shaft seal assembly for stirred enclosed vessels. For example, the bearing layout must ensure that, however much the vessel deflects, the shaft must still remain concentric; bearings should be as far apart as possible with the lower bearing as close as possible to the seal. The unsupported shaft lengths should be as short as possible, and tapering at some distance below the lower bearing helps to keep whip away from the seal. A further important point is that the bearing must withstand the thrust of the shaft, whether this is upwards or downwards.

Additional useful advice was given in this paper: first a seal takes a little time to run in, a good installation may give two years' service without attention, and it should be allowed to go as near to a break-down as one would dare; it should on no account be stripped for inspection unless a failure is expected. The fitting and maintenance of seals themselves requires systematic training.

Factors in Valve Design

Mr. H. E. Charlton stated that tightness required of a valve varies according to the application. A number of physical and mechanical factors affect valve tightness; in the former category are the fluid properties of surface tension and viscosity, the presence of viscous material between the seating faces, the resilience of non-metallic and the elastic properties of metallic seating materials. To these should be added the effect of intermolecular forces, and sealing by the freezing of a low-melting-point material around the seat.

Of the mechanical factors, among the most important are the accuracy and surface finish of valve and seat, alignment of the valve parts, proper guiding of valve on to seat,


PETROLEUM AND CHEMICAL PLANTS
from
Planning
to
Completion
McKEE HEAD WRIGHTSON LTD
TEESDALE HOUSE
16-26 BALTIC STREET
LONDON EC1
P4710

TABLE

Gate Valves		Seating Pressure due to			Factors Influencing Seat Tightness						
					1	2	3	4	5	6	7
		System Δp across valve		Closing mechanism	Surface tension	Viscosity	Sealing viscous material	Resilience soft materials	Elastic strain metals	Sealing by freezing	Intermolecular forces
Wedge	Solid wedge	√	√	√	√	√	—	—	?	—	?
	Split wedge	√	√	√	√	√	—	—	?	—	?
	Soft seating rings	√	√	√	—	—	—	√	—	—	—
Parallel Slide	Spring loaded	√	√	—	√	√	—	—	?	—	?
	Wedge closing	√	√	√	√	√	—	—	?	—	?
	Lubricated	√	√	—	—	—	√	—	—	—	—
	Soft seating rings	√	√	√ If wedge type	—	—	—	√	—	—	—
Plate	Resilient packing	√	√	—	—	—	—	√	—	—	—

adequacy of the mechanical force keeping valve and seat in contact, suitability of materials for preventing galling and for reducing damage through presence of foreign matter.

The influence of these factors upon tightness are expressed in tabular form for various types of valve. (See Table I, one of four given by the author).

The Effect of Surface Tension

Valves which depend upon surface tension and viscosity are suitable for liquids and dry gases, but less so for dry gases. Surface tension has two effects upon valves; it can completely seal off the flow of fluid, provided the sealing faces are close enough together and if the differential pressure × 68,948 is not greater than 2 × surface tension (dynes/cm) ÷ distance between valve and seat (cm). The other effect of surface tension is an adhesion between valve and seat when the surfaces are in close proximity.

Interfacial tension is important if the surfaces have been wetted by a fluid insoluble in the line fluid; thus, for example, if the seating surfaces are covered by a film of kerosene and if the line fluid is water, the valve may leak badly unless the kerosene is removed.

Commenting upon the extending range of temperature and pressure, Mr. Charlton referred to the valuable standards published by the B.S.I. and the A.S.A. The appropriate British standards show that a standard 2500 gate or plug valve can be used at ambient temperatures up to a pressure of 6000 psi, and if made in alloy steel may be used at lower pressures up to 650°C; also non-ferrous and alloy steel valves are often used down to −200°C.

Of the other types of valve, lubricated valves are not normally used above 250°C and needle valves are satisfactory for liquids and gases at very high pressures.

Size also limits the type of valve as shown below.

TABLE II

Valve Type	Usual Range, Depending on Pressure
	(in.)
Gate valves	½ to 72
Plug valves	¼ to 18
Globe valves	⅛ to 12
Needle valves	⅛ to 2
Butterfly valves	8 to 72

With the extending limits of operation and the need for greater corrosion resistance, it becomes more difficult to find non-galling materials, and is unfortunate that some of the more corrosion-resisting materials are poor resisters of galling. However, a hardness differential of about 100 Brinell between valve and seat is a condition likely to reduce galling; another method is to stellite face valve and seat.

Sealing the Spindle

Most valves employ stuffing-box seals at the spindle and this is in many cases satisfactory. In addition, a good quality valve will have a back seat as standard so that gland leakage is minimised, when the valve is in the fully open position, and allows repacking under pressure.

Another method of sealing the spindle is to use "O" rings—an effective method when the spindle is well finished or to cap the gland if the valve is to be used occasionally only. Finally, when a high degree of tightness is required, a bellows sealed gland may be used. The difficulty here is that the bellows is a relatively weak component and has a limited life, consequently, efforts are being made to improve the qualities of bellows. Thus Mr. Charlton demonstrated an experimental bellows which withstood pressures >2000 psi.

Wire drawing, i.e., damage to seating surfaces through the passing through of foreign particles or liquid droplets at near-sonic velocity, can be eliminated by a special design of valve which prevents the first pressure drop from being taken on the main seat and the high velocity occurs as a secondary clearance where damage is of no consequence. The worst that can happen to a valve is damage to the seating surfaces through the presence of hard foreign particles; this may require the valve head seating to be repaired or replaced. Hard facing of surfaces and arranging for them to slide over one another will lessen the risk of such damage.

Sealing Against Vacuum

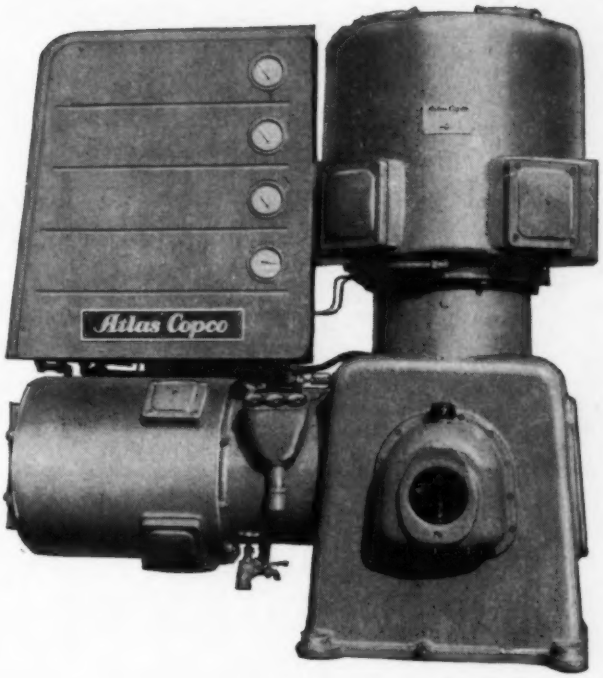
"High Vacuum Closures" was the subject of the paper given by Mr. A. W. Avery, of the U.K.A.E.A., who gaseous diffusion plant is the largest vacuum system in Western Europe. Rolled plate or forgings are used for vacuum tightness, because castings are porous. The plants are tested for vacuum tightness, and to minimise out-gassing even the least porous materials must be kept clean during fabrication and be degreased before assembly. Welded joints are preferable and joints should only be flanged if they are to be broken and re-made frequently. Mild-steel joints are welded by the electric arc process, aluminium and stainless steels by the inert gas/metal arc process. The quality of the weld varies with the position of the welder making it and trapped gas in welds must be avoided. Flanged joints should contain fully trapped rubber rings, the flanges should be very smooth and clean, and the metal faces should touch when they are tightened; also the packing is so constructed that the joint can be tested for vacuum tightness without evacuating the whole plant. The sleeve coupling for pipes has some faults and is used for temporary connections; the commercial coupling is better and the interspace block coupling is used mainly for connections for instruments and for sample lines. For valves, seals are required along the spindle and at the valve seat. The spindle may be sealed by a packed gland, by "O" rings, diaphragms or bellows, depending on the operating conditions. The best valve seats are rubber to metal or PTFE to metal; the metal must have a lapped and polished finish and it must be kept clean.

Here's Air Power at **ROCK BOTTOM** cost

ER6 Heavy-Duty Compressor for reliable 3-shift operation

Atlas Copco's ER6 compressor delivers air at the lowest possible cost. Designed to incorporate *every* economy factor, it combines the lowest possible running costs with low installation costs and a space saving design.

The ER6 delivers 1,075 cfm at 100 psi (30.4 m^3/min at 7 kg/cm^2) for a power consumption that is absolutely rock bottom. Thanks to a new type of intercooler, water consumption is only 440 imperial gallons (2,000 litres) per hour—a *quarter* the consumption of most similar machines. The ER6 is compact. Occupying only half the space usually required for machines of its capacity, it saves expensive factory space. In addition, installation costs are lower as new, cheaper installation methods are employed.

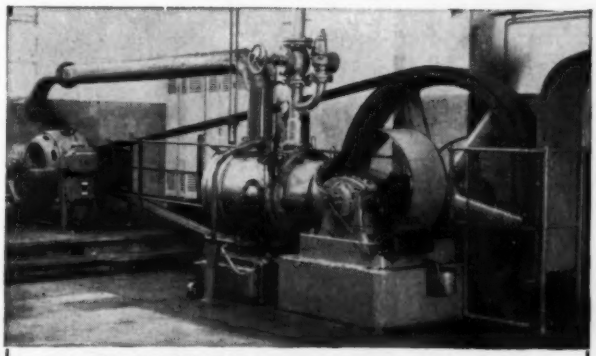


RANGE OF STATIONARIES

From 2.5 to 20,000 cfm, there is an Atlas Copco stationary compressor to suit every requirement. Whatever the design factor—compactness, low installation cost, low operating cost, or a combination of all three—Atlas Copco stationaries are high-performance machines you can rely on.

Sales and Service in Ninety Countries

Represented in ninety countries, Atlas Copco is the world's largest organisation specialising solely in compressed air equipment. Products include stationary and portable compressors, rock drills, loaders, hoists, air tools and paint-spraying equipment. Wherever you are, the international Atlas Copco group offers expert advice and provides a complete after-sales service.



Built to last. This Atlas Copco compressor was installed at the Bofors engineering works (Sweden) in 1907. It is still in operation.

WRITE FOR THE LEAFLET

Leaflet E1127 gives full details of the ER6 compressor. Write for a copy to your local Atlas Copco company or agent or to the address at the foot of this advertisement.

Atlas Copco puts compressed air to work for the world

Atlas Copco AB, Stockholm 1, Sweden. In the U.K. Atlas Copco (Great Britain) Ltd., Hemel Hempstead, Herts.

BC 88

NOMOGRAM SHOWING THE DIAMETER FOR HEAT EXCHANGER TUBE BUNDLES

The nomogram solves the equation

$$D_E = \frac{4\left(S_T . S_L - \pi \frac{D_O^2}{4}\right)}{\pi D_O}$$

where D_E = equivalent diameter;

S_T, S_L = dimensions of tube matrix as shown in the diagrams; and

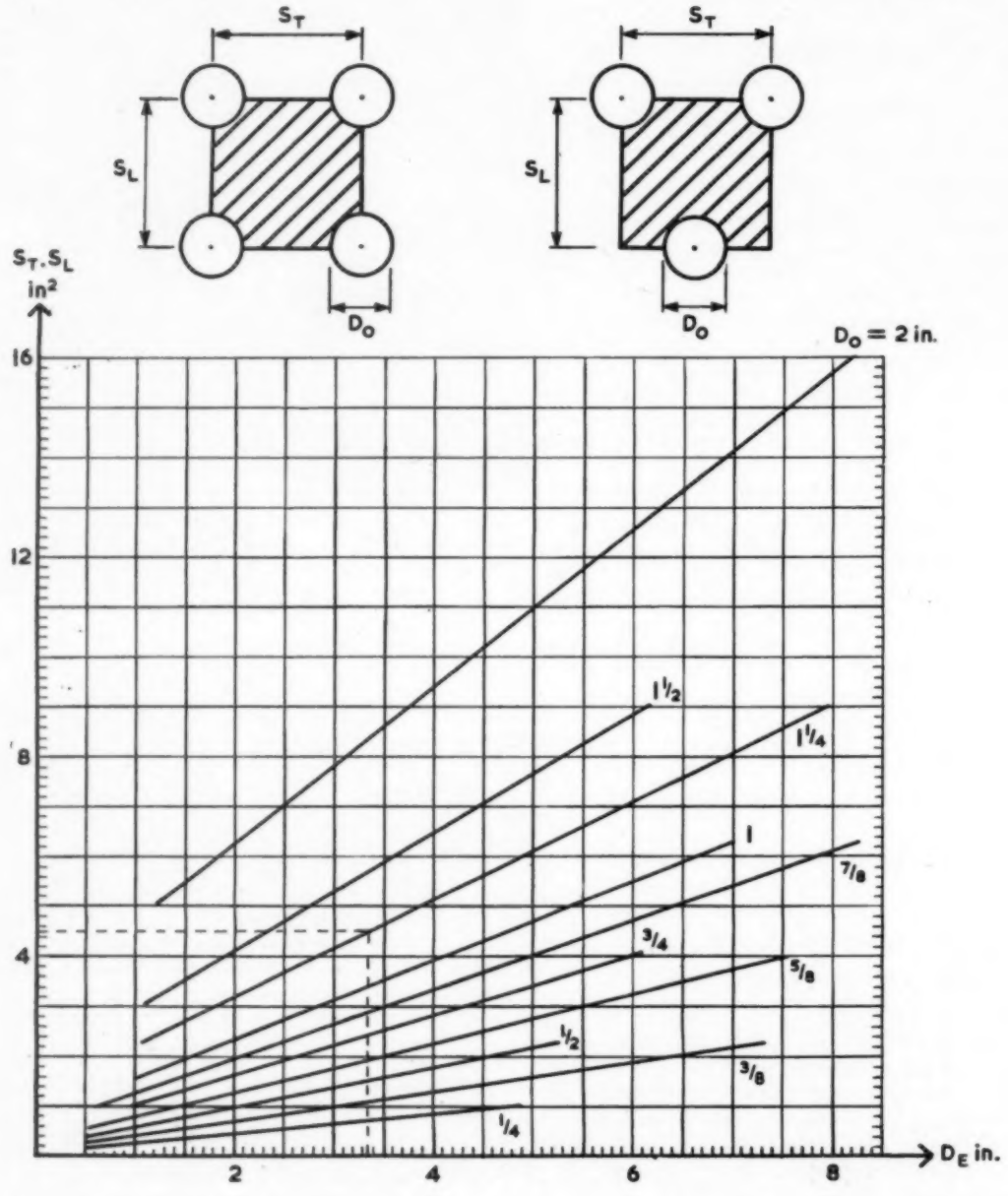
D_O = outside diameter of tubes.

The broken lines indicate how to use the nomogram.

Example: $S_T = 2$ in. $S_L = 2\frac{1}{4}$ in.

$\therefore\ S_T S_L = 4\frac{1}{2}$ in.^{2} $D_O = 1\frac{1}{4}$ in.

$D_E = 3.35$ in.



British Chemical Engineering

NOMOGRAM NO. 51

BCE 8189 for further information

CHEMICO BUILDS NITRIC ACID PLANT IN SIX MONTHS

AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY

It took just six months for Chemico to successfully complete a 120 ton per day nitric acid plant in Lawrence, Kansas. Until the client gave his final "go-ahead," not an hour of drafting or engineering had been done on the project—not a single piece of equipment had been placed on order. Yet, six months from that date, the plant finished its acceptance test run, producing at above rated capacity.

With 34 nitric acid plants in operation all over the world, and three more in the design stages at this very time, Chemico maintains its position of leadership in this field. In building plants to produce Ammonia, Urea, Nitric Acid, Acetylene, Methanol, Hydrogen, Sulfuric Acid and other chemical and petrochemical products, Chemico is setting new standards for the entire engineering industry.

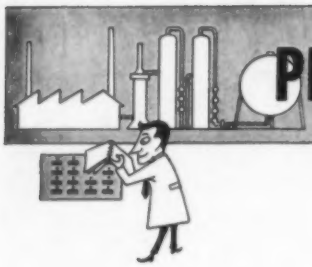
This six month performance for a nitric acid plant follows closely the recent successful completion of an ammonia plant in ten months. It is not just the time factor alone which sets Chemico plants apart, however. Chemico clients know that they are buying efficient, economical, proven processes which assure ease of start-up and simple, safe operation. If you are considering building a new plant or enlarging present process facilities, let Chemico help you get the most for the capital you invest. Write for the General Bulletin which describes the wide range of Chemico's activities.

CHEMICO

CHEMICAL CONSTRUCTION (G.B.) LIMITED
9 Henrietta Place, LONDON W.1

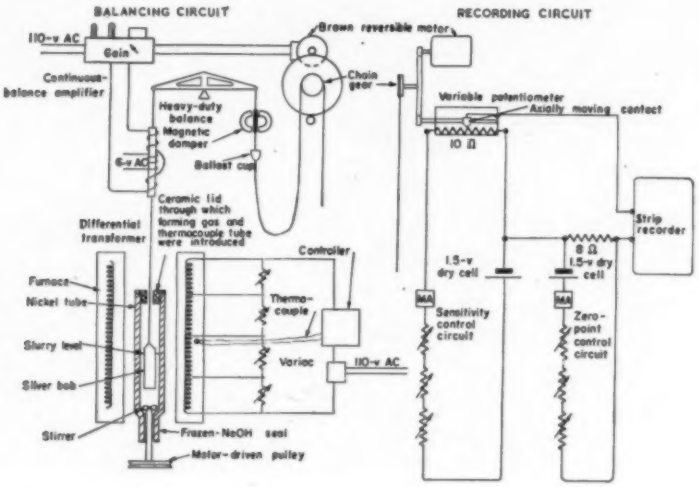
A subsidiary of Chemical Construction Corporation, New York, N.Y. U.S.A.

NEW YORK · CHICAGO · DALLAS · HOUSTON · PORTLAND, ORE · TORONTO · PARIS · JOHANNESBURG · TOKYO



PROCESS ENGINEER'S NOTEBOOK

Measuring settling rates at High Temperatures



AN EXPERIMENTAL PROGRAMME for evaluating the engineering problems of circulating an $NaOH\text{-}UO_3$ slurry, which was being considered as a combined moderator, coolant and fuel for a high-temperature homogeneous reactor, required the measurement of slurry particle size distribution and its variation with temperature.*

For this purpose, a completely automatic recording balance was devised for measuring settling rates of the slurries at temperatures around 800°F. The diagram shows the arrangement of the various components of the instrument. In essence, it consists of a chainomatic balance in which the balance position is maintained automatically.

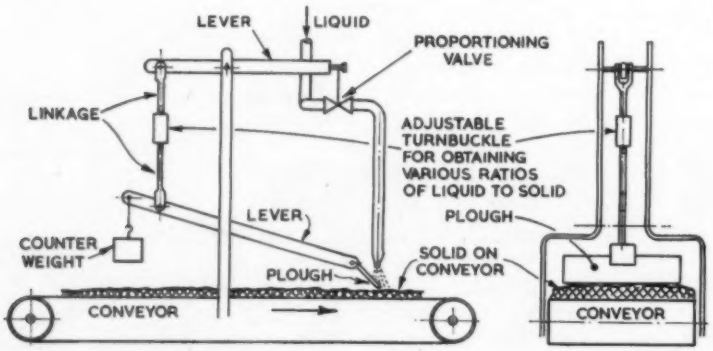
A deviation from the balance position is caused by a change in the buoyant force on a cylindrical silver bob partially immersed in the slurry. This change, which results from a decrease in the effective density of the slurry by the settling of particles, is detected by a differential transformer. The output of the latter is amplified and fed into a reversible motor which moves the chain to restore balance. The chain is linked to a variable potentiometer, the position of which is recorded by a millivolt recorder. The resulting weight-difference curve indicates the rate at which the solids settle out of the slurry.

* Report B.M.I. — 867. Investigation of the behaviour of $NaOH\text{-}UO_3$ slurries in small flow loops. J. H. Stang, J. F. Lagedrost, E. M. Simons, R. W. Dayton. Battelle Memorial Institute. 1960.

Method of Adding a Liquid to a Solid continuously

IT IS OFTEN NECESSARY for a proportioned quantity of liquid to be added to a mass of solid material which is transported on a conveyor belt. One such case where this facility is required is where oil is to be added to coal in preparation for carbonisation. Another is where the addition of water to iron oxide is required for preparing the latter for use in gas purification. One effective method of performing the addition is shown in the accompanying sketch. The device consists of a plough attached to a lever arm, the plough being suitably counterbalanced. The plough is in contact with the solid material on the conveyor, and as the quantity of the material upon the belt varies, so will its contour. The plough responds to such changes, and its altered position will be transmitted by a system of levers to a proportioning valve through which the liquid is fed. If required, the ratio of liquid to solid can be changed by adjusting the extent of the valve opening relative to the position of the plough. For this purpose a turnbuckle is provided. The proportioning valve may be adapted from a simple float-operated valve.

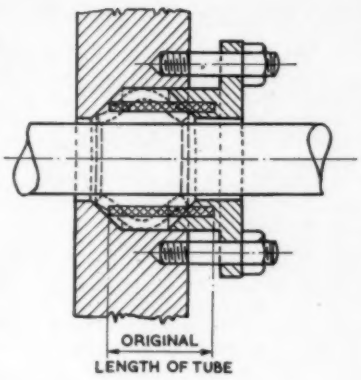
R.H.U.



A simple Mechanical Seal for pumps or agitators

NUMEROUS PACKINGS and mechanical seals are available for use under either acid or alkaline conditions, but these are not so effective under abrasive conditions or against solvent vapours.

With the usual type of packed gland, the packing consists of some form of woven, long-stranded asbestos, loaded with lubricant to reduce the friction. But since the lubricant is unfortunately easily soluble in solvents such as benzene or carbon tetrachloride, the asbestos is left completely dry and unresistant to abrasion. To a somewhat lesser extent the normal mechanical seal is subject to the same shortcoming, to counteract which the following simple gland was developed.



This is based on the well-known Curtis flexible pipe joint and in this application the packing of the normal gland is replaced with a length of unplasticised polythene tube.

The wall thickness was $\frac{1}{8}$ in. and the clearance around the shaft approximately $\frac{1}{16}$ in. The tube is inserted in place of the packing and is compressed into the stuffing box by the gland follower. This packing has sufficient flexibility to act as a mechanical seal, is resistant to all solvents, to abrasives, acids and alkalis and has considerable self-lubricating properties.

F. MOLYNEUX

Relief Valves that operate independent of back pressure

THE SIZING OF A closed system, collecting vapours released by conventional-type relief valves, is governed by the maximum permissible variable back pressure allowable at the valve outlet.

The conventional type of spring-loaded relief valve (plate "a") will maintain its blowing pressure and capacity against a variable back pressure of 8% of its set pressure. If the variable back pressure exceeds 8%, then it interferes with the valve operation by excessive loading of the exposed area of the back of the valve disc, thus increasing the spring setting and reducing the original capacity based on 10% over pressure.

To overcome this problem, a bellows was installed on the back of the disc in order to balance out the unequal area exposed to the back pressure (plate "b"). These bellows were also used to keep viscous fluids away from the spring chamber. This balancing out of areas by the bellows has been very successful, and the bellows valve can be used for variable back pressures up to 45% of the set pressure, allowing the valve to attain full lift and reach its rated capacity at 10% over pressure.

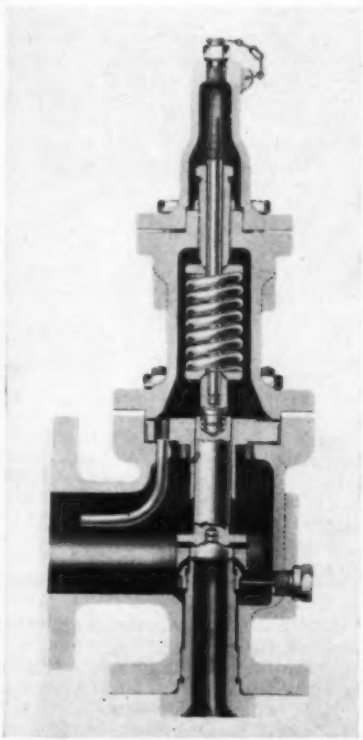
It was felt that for some gas services the reliability of the bellows might not be adequate due to possible work hardening of the stainless steel, and the design was modified to allow for a ruptured bellows which would automatically cancel out the balancing effect.

In conjunction with the Shell engineers, Dewrance & Co. Ltd. have developed and are produced this bellows valve fitted with an auxiliary piston in the spring chamber (illustration "c"). This piston is of equal area to the bellows, and in the event of the bellows rupturing the leak through the bellows acts on the lower face of the piston, thus maintaining the balancing-out effect lost by the ruptured bellows.

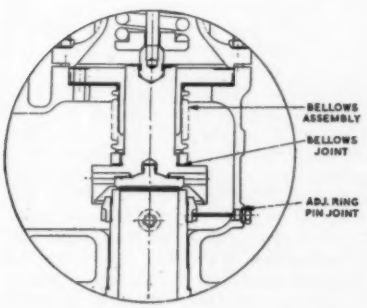
This piston would be adequate by itself without the bellows beneath it, but it is desirable to retain the bellows, as a slight leak may occur past the piston ring into the vented bonnet, causing a continuous leak of inflammable or poisonous vapours into the atmosphere.

This design has proved satisfactory and is in use at Shell Haven and Stanlow refineries, and is now generally available.

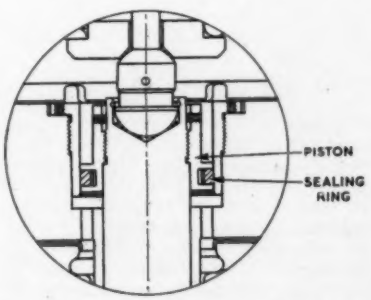
Costings of particular installations in the U.S.A. show savings of some $20,000 on a discharge system using these balanced relief valves.



(a) Conventional spring loaded relief valve without modification.



(b) Relief valve with bellows fitted behind disc.



(c) A further development—the addition of auxiliary piston

Book Reviews

Thermodynamics
by Herbert B. Callen
John Wiley & Sons, Inc., New York, Chapman & Hall, London. 1959, 376 pp., 70s.

THIS is a book written by a physicist who is known for his work on the thermodynamics of thermoelectric and thermomagnetic effects, and for important work in the field of the thermodynamics of irreversible processes. It is a book for the specialist, and although it covers familiar ground in many places, the treatment is often so formal as to render it almost incomprehensible to the general reader. As an introduction to the subjects on which the author is an authority (thermoelectric and irreversible phenomena), the book will not be of much help to the chemist or engineer, as it is obviously written for the theoretical physicist. The author's claim that students at the University of Pennsylvania have successfully taken a course based on the book without experiencing any special mathematical or conceptual difficulty is astonishing to say the least. It is doubtful whether many readers of *British Chemical Engineering* will willingly submit themselves to the discipline which this arid approach demands.

P. H. CALDERBANK

Radioisotopes in Science and Industry
Report of the U.S.A.E.C., January, 1960 176 pp., 9s.

THIS special report on radioisotopes is noteworthy because it summarises the major milestones in isotope development and their impact on scientific understanding and industrial productivity, it has a full and informative series of appendices and it is a document cheap enough to receive wide distribution. The report is divided into ten main sections covering the use of isotopes and radiation in agriculture and plant studies; medical, physical and chemical research and in the development of new applications and plant processes.

One is struck by the number of items of chemical engineering interest which have not been adequately reported in the U.K. In physical chemistry isotopes have been used to elucidate the Friedel-Crafts reaction and the extent to which catalysts actually enter into the process and for studying chemical kinetics in exchange reactions such as those between bromine and halogenated methanes. Tracer techniques have been developed to investigate surface reactions (problems in plating, detergency, corrosion, adhesion and degassing); catalysis (fundamental properties, action of accelerators) and in diffusion (particularly in non-homogeneous structures such as metals and alloys). The flotation of minerals is a basic problem suitable for this type of investigation and the mechanism of the interaction between reagents and minerals has been studied by the use of micro-auto radiography for examining the irregularities in the distribution of xanthogenates on the surface of sulphide particles.

Chapter VI is devoted to the development of new techniques. It is impossible to review adequately the large number of different developments, but reference should be made to the use of isotope tracers for studying washing and cleaning processes in the food industry; the study of particle mechanics in slurries (particularly, the fluidisation of coal and catalysts with flowing gas and liquids); the performance study of platinum catalysts during hydrogenation reactions; the measurement of surface area and particle size of powders; quality control in the large-scale production of, for example, cement; and finally studies on a wide variety of separation processes. One can single out the measurement of liquid levels in sealed tanks as a well-known problem particularly suitable for radioisotope techniques. Here a back scattering technique is described in which liquid levels are claimed to be measured to $\pm\frac{1}{4}$ in. by the use of source and detector lowered into a tube sealed in the tank top.

The application of direct radiation is extensively described, although most of the work has already been reported. This complete account does, however, underline the emergence of a new radiation process technology which should be familiar to a large audience. In any discussion of these new developments economics is the deciding factor, and the report includes a useful section showing awareness of the importance of economic evaluation and the factors which must be taken into account.

The report is well written and produced and is worth every penny of the 9s. It should be in the library of any group concerned with process plant study or development.

B. E. ELTHAM

Heat Bibliography, 1958
H.M.S.O., London, 281 pp.,15s.

THIS bibliography is the fifth of a series produced by the Heat Division of the National Engineering Laboratory, which together cover the period 1948-58. The present volume consists of 281 pages compiled under 51 main headings. These are chosen to include all the main aspects and many of the ramifications of the subject of heat. The introduction states that the bibliography contains only material noted in the N.E.L. during the year 1958, and is not necessarily complete so far as work published in that year is concerned. It also contains certain references to papers published in earlier years.

The fact that the bibliography is incomplete cannot but reduce its value as a source of reference. It appears to the reviewer that with comparatively little extra trouble on the part of the editorial staff, such as cross-checks from the monthly editions of *Index Aeronautics* and like sources, the publication could be made much more reliable. This suggestion is all the more cogent now that a charge of 15s. is made for the bibliography, previous editions having been distributed free.

Progress in Non-destructive Testing, Volume 2
Edited by E. G. Stanford and J. H. Fearson
Heywood & Co. Ltd., 1960. 250 pp., 55s.

OVER recent years the study of the techniques of non-destructive testing has been greatly intensified and its importance has been fully realised in British industry, especially in the fields of aircraft manufacturing and atomic energy, where the slightest fault in the materials used could prove disastrous. Flaw detection, however, as pointed out by the editors both in this volume and its predecessor, forms only a small part of non-destructive testing, which must include the examination of the physical, chemical and even biological conditions of solids, liquids and gases. In spite of the importance of the subject, very few books on it are available, and the appearance of the series on *Progress in Non-destructive Testing* is welcome.

Like Volume 1 of the series, the second volume reports on recent scientific work on the subject and, although it will appeal primarily to those engaged in research and development, much of its material can be appreciated by the technician. There are seven sections, each by different authors, which include "Radiology with High-energy X-rays"; "The Mechanical Testing of High Polymers"; "Application of Electrical Methods for the Detection of Flaws and for the Study of Metal Structure"; "The Uses of Radioactive Isotopes in Non-destructive Testing"; "Defect Assessment using Ultrasonic Waves"; "Studies of Ageing and Precipitation in Metals using Anelastic Damping Measurements"; and the "Application of Paramagnetic Resonance to Non-destructive Testing". The last two chapters may prove heavy going for the non-scientist.

Although, as one must expect from a work of this nature, the treatment is uneven from the points of view of both style and levels of subject-matter, the standard throughout is uniformly good, each author being an expert in his work. The pages are crammed full of useful information, and with one excusable exception, numerous references are appended to the end of each chapter. In particular, Mr. J. F. Cameron is to be commended for his lucid chapter on the "Uses of Radioactive Isotopes".

There is no index, but it is questionable whether or not the well-laid-out lists of section headings at the beginning of each chapter provide a satisfactory alternative. The editors are to be congratulated in maintaining the high standard they have set in Volume 1 and it is gratifying to note that, although it is only 10 pages shorter than its predecessor, the price has been reduced by 5s.

J. BLITZ

B.S.3016:1960 — Part 2: Low-pressure Regulators for use with Propane Gas.

MATERIALS, CONSTRUCTION, performance and testing requirements for low-pressure single-stage or second-stage regulators for vapour phase propane up to 20 in. w.g. outlet pressure (51 g/cm^2) are specified. Propane gas is defined as a mixture consisting predominantly of C_3 with some C_2 and C_4 hydrocarbons.

Miss Neasden is very hot on some subjects...

but not as hot as us... (speaking industrially of course)

industrial heating by

Electrothermal®

Write or telephone your problem to:—

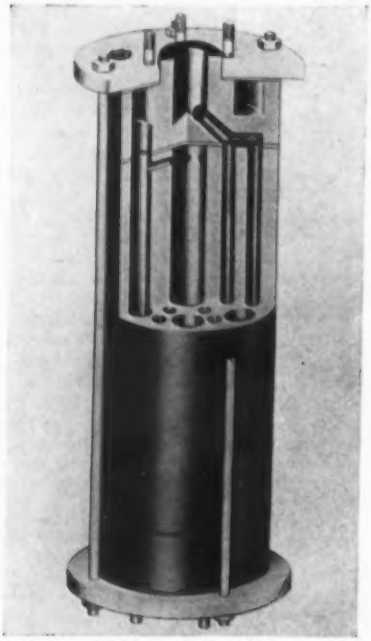
ELECTROTHERMAL ENGINEERING LTD. LONDON. E.7

Telephone: GRAngewood 9911
Telegrams: Electrotop, London

MANUFACTURERS OF INDUSTRIAL AND LABORATORY HEATING EQUIPMENT
SCIENTIFIC INSTRUMENTS · ELECTRONIC COMPONENTS · PLASTIC MOULDINGS

PLANT EQUIPMENT NEWS

New-type Impervious Graphite Heat Exchanger



This is designed especially as an economical unit for limited volume heating or cooling requirements, such as encountered in the plating industry. It employs a single monolithic piece of graphite for the heat-transfer cylinder, in which both the heating and cooling passages are drilled parallel to each other. Corrosives contact only the impervious graphite which is unaffected by all chemicals except a few highly oxidising agents. In addition, this material possesses a high rate of thermal conductivity — 1020 Btu/hr/ft²/°F/in.— and is immune to thermal shock. Temperatures to 340°F can be accommodated at pressures to 75 psig hydrostatic (50 psi steam). This new unit is composed of the heat-transfer section with unique header domes at each end. These headers keep the two mediums separated from each other, thus eliminating piping connections into the side of the unit. No shell is required. The entire exchanger is held together with four full-length tie-rods. **Falls Industries Inc., Engineering Department, Aurora Road, Solon, Ohio, U.S.A.**

BCE 8239 for further information

Glass Beads as Grinding Medium

One advantage of Ballotini glass beads over higher density alumina spheres for grinding purposes is that the former can be obtained in a very wide range of closely graded sizes. Another advantage is that glass is almost pure crystal and therefore contamination of product would be nominal. One well-proven application of glass beads is in the grinding of pigments. The English Glass Co. offer machine-made glass balls ¼ in., 1 in. and 1¼ in. in diameter. This is in addition to a range of beads, the smallest size being 0.04 mm in diameter, whereas the largest is 12 mm. In some parts of this range, the step from one size to another is no more than 0.1 mm, and towards the upper end of the range, i.e., from 2-12 mm, the size of bead increases in 1-mm steps. Prices are in the range of 7s. to 19s. per lb., and in the smaller sizes the beads are available in various colours. **The English Glass Co. Ltd., Empire Road, Leicester.**

BCE 8240 for further information

Cationic Chemicals as Flocculants

Aqueous suspensions containing particles with negatively charged surfaces lend themselves to flocculation by cationic chemicals, provided that these are water-soluble and sufficiently low-priced to warrant their use. Such chemicals are quaternary ammonium salts and diamine acetates. A typical commercial application is the flocculation and settling of colloidal silica where other conventional flocculants have failed. Mineral silica, clays and iron ore suspensions are other materials where cationic flocculants give good results, the amounts used varying from 0.001 lb. to 0.5 lb. (0.5-250 ppm) of chemical per ton of suspended solids. A particular advantage of the quaternary ammonium salts is that, simultaneously with their use as flocculants, algæ growth is effectively controlled. Where algæ growth is a problem the use of this type of flocculant is therefore exceedingly economic. **Armour Hess Chemicals Ltd., 4 Chiswell Street, Finsbury Square, London, E.C.1.**

BCE 8241 for further information

Vibratory Conveyor

At the Mechanical Handling Exhibition an electro-mechanical vibratory conveyor was shown based on the use of English Electric vibrator motors. Two motors are geared together but contra-rotating. This arrangement, giving a fully counter-balanced drive, is claimed to ensure that no vibrations are transmitted to the support structure. Both motors are independently driven and it is said that no load is taken on the synchronising gears. The arrangement imparts approximately 1500 oscillations per min. to the conveyor. The motors are so disposed that they produce the oscillations at an angle, as indicated, and the material being conveyed moves upward and forward in a series of "jumps", reducing wear of the conveyor trough due to sliding of the material.

Materials at temperatures up to 600°F can be conveyed with low power requirements. Applications are envisaged in the chemical, steel, gas and electricity and food industries. The speed of flow of material is based on approximately ¼ in. amplitude of vibration and is approximately 60 fpm. The conveyor will work efficiently on inclines up to approximately 18 degrees depending on type of material. A 6-in. "U" section or tube can handle up to 400 cu. ft/hr; an 8-in., 800 cu. ft/hr; a 10-in., 1300 cu. ft/hr; and a 12-in. "U" section or tube, 1800 cu. ft/hr. **Thos. W. Ward Ltd., Lancaster Place, Strand, London, W.C.2.**

BCE 8242 for further information

Centrifugal Pumps

A number of alterations have been announced in the Firth Cleveland range of self-priming centrifugal pumps.

The capacity of the model 1 MP 1-in. lightweight pump has been increased from 1000 to 1200 gph. Maximum lift and head remain the same at 20 ft and 65 ft respectively.

The model 1 ME 1-in. ¼-hp lightweight pump with 1000 gph capacity is now rated with a 25-ft head.

Replacing the former model 4 M is a new model 4 MP 1½-in. pump. The engine horsepower has been increased to 1.9 and the maximum head from 70 ft to 90 ft. Maximum suction, lift and capacity remain the same at 25 ft and 4000 gph respectively.

The former model 6 M has also been replaced—by the model 6 MP 2-in. pump. This has 6000 gph capacity, and its maximum head has been increased from 98 ft to 120 ft.

The model 15 MD 3-in. automatic centrifugal pump is now available with 3¼-hp or 10-hp Petter PC.1 or PC.2 engines, giving capacities of 15,000 and 20,000 gph respectively and maximum heads of 45 ft and 110 ft respectively.

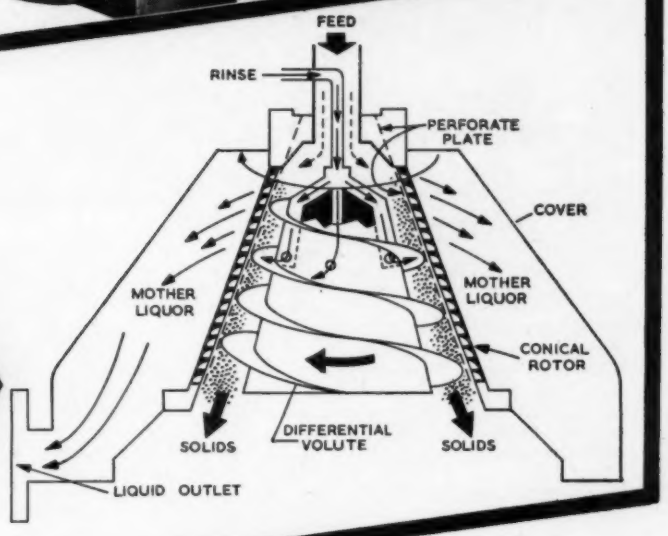
Final alteration in the range is to the model 15 MP 3-in. standard wheel-mounted pump. This model is now also available with alternative power units. With a 4.7-hp Villiers engine, its capacity is 15,000 gph, while its maximum head has been increased from 75 ft to 80 ft. With a JAP 8-hp engine, its capacity is increased to 19,000 gph, maximum head being 115 ft. **Firth Cleveland Pumps Ltd., Premier Works, Earl Shilton, Leics.**

BCE 8243 for further information

Balanced Stop Valves

A new range of balanced stop valves is announced by British Ermeto Corp. Ltd. Incorporating a special high-pressure joint, these valves are designed for use on high-pressure hydraulic and pneumatic systems. All are completely balanced and are fitted with replaceable nylon seats, have non-rotating splindles and non-rising

Now the **Super-Screen** joins the Sharples range



The arithmetic of success

A well proved Centrifuge pioneered in the European chemical and process industries — + Sharples manufacturing and chemical engineering experience = The New Sharples Super-Screen

● This is important news for everyone in the process industries. You ● ● can now have the best of both worlds. Installations in many parts of the world testify to its proven application on crystalline materials, but already our development men have found many exciting new applications. Write to-day for further information on this new centrifuge or about your own separational problems.

SHARPLES

SHARPLES CENTRIFUGES LTD · TOWER WORKS · DOMAN ROAD · CAMBERLEY · SURREY

Tel: Camberley 2601. Telegrams: 'Superspin' Camberley

PLANT EQUIPMENT NEWS

handwheels. The operating threads are external to the spindle seals.

The valves can be supplied in mild steel, high-duty bronze or stainless steel. They are available with Ermeto ends for use

with nominal bore piping from ¼ to 1¼ in. diameter. They are also available with B.S.P. female end connections from ¼ to 1¼ in., and special end connections can be effected by the use of stud couplings or stud adaptors with the B.S.P. range. **British Ermeto Corp. Ltd., Maidenhead, Berks.**

BCE 8244 for further information

Reciprocating Compressors

Vertical reciprocating compressors in a new standard range being marketed as type 300/A are now being produced by the Bryan Donkin Co. Ltd.

Replacing their earlier range of compressors, these are of modified design and are said to have increased operating efficiencies. Pressures obtainable with the new models are (for 6-in. stroke) 50 psig single stage, 250 psig two-stage and 1200 psig three-stage. For the 8-in. stroke model, the figures are 45, 225 and 975 psig respectively. For the 12-in. stroke model, figures are 40, 200 and 750 psig.

The 6-in. stroke compressor can be

supplied as a single-, two- or three-crank machine and the 8-in. and 12-in. versions are made with either two or three cranks. Maximum flow of free air obtainable with the 12-in. stroke compressor at a discharge pressure of 10 psig is about 3600 cfm.

Suction and delivery valves of the cylinders are disposed around the cylinder walls, improving their accessibility and that of the cylinder and piston. The lubricating oil system is equipped with a centrifugal air cleaner driven by oil pressure. A water-cooled oil cooler is incorporated in the baseplate. The compressors are said to be completely dust- and weather-proof. **Bryan Donkin Co. Ltd., Chesterfield.**

BCE 8245 for further information

Process Control Equipment

At the heart of a range of equipment for process control is the Microsen balance—a measuring and transducing device for changing signals due to measurements into correspondingly amplified output signals. The design of these electronic instruments is claimed to utilise all the advantages inherent in the electric transmission of measurement and operational signals. Instrument lag in control loops is virtually eliminated. The system employs direct current signals, carried by simple two-wire circuits. Common earth may be used in the case of multiple installations. These signals are not affected by induced alternating currents or varying line resistance up to a maximum of 3000 ohms. Equipment available includes a miniature strip chart recording controller, a miniature indicating controller, vertical scale indicating controller differential pressure transmitter (with Barton D.P. cell) and miniature strip chart recorder available with single pen recorder, two-pen recorder, current and voltage recorder or two-pen current and voltage recorder. There is also a transmitting potentiometer in a number of models designed for thermocouple inputs millivolt inputs, resistance bulb inputs and for strain gauge inputs. The range also contains other transmitters and transducers. **Dewrance & Co. Ltd., Great Dover Street, London, S.E.1.**

BCE 8246 for further information

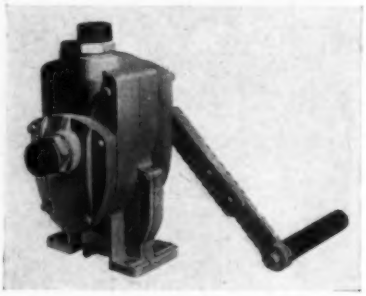
Packless Solenoid Valves

Now being manufactured in Britain under licence from the U.S.A. are ASCO solenoid valves designed for low-temperature and high-pressure use. The range includes two-, three- and four-way valves in a number of sizes. They are said to be suitable for controlling air, nitrogen, oxygen, helium and hydrogen as liquids or gases. The valves are designed to utilise poppet seats and discs (consisting of metal-to-metal or soft seat) to provide tight seating. This particular feature is claimed to eliminate leakage and sticking difficulties commonly experienced in valves of spool or balanced orifice construction requiring close mechanical clearance or synthetic seals in controlling leakage. Construction in packless (hermetically sealed). Coils are replaced without shutting off or opening pressure connections or removing the valve body from the pipeline. The complete range covers differential pressure from vacuum to 5200 psi and temperatures from −320°F to +600°F. **Dewrance & Co. Ltd., Great Dover Street, London, S.E.1.**

BCE 8247 for further information

Hand-operated Semi-rotary Pump

The need for an efficient, hand-operated, self-priming, semi-rotary pump is fulfilled by a new range of G.T.E. rotodynamic pumps. The suction performance of these pumps is outstanding. There is, for example, a model in the range which has a capacity of 150 gpm, which achieves a 5-ft static delivery head with a suction



lift of 32 ft. A similar pump within the range on test gave a discharge rate of 8 gpm and achieved a manometric suction head of just under 33 ft—an exceptional suction performance. All pumps within the range are compact, portable and easy to install. Prices range from £24 upwards. **General Trade Equipment Ltd., 82/90 Seymour Place, London, W.1.**

BCE 8248 for further information

High-pressure Flow Indicator

The success of the standard Arkon flow indicators—a simple visual indication via a moving spindle of oil or water flow—led to a demand for a version which would withstand very high pressures. Walker, Crosweller & Co. Ltd. now announce the introduction of this type of Arkon flow indicator fitted with a high pressure cap which will take pressures up to 200 psi. **Walker, Crosweller & Co. Ltd., Cheltenham.**

BCE 8249 for further information

Horizontal Packaged Boilers

A new range of horizontal "packaged" boilers, operating on either coal or fuel oil, and designed for steam or high-pressure hot water, has been introduced by Cochran & Co. (Annan) Ltd.

Known as Sinupac, the boilers are available from 3750 to 37,000 lb./hr. are of welded construction, and each is supplied mounted on a bed-frame which carries also the control panel and feed pump.

Coal- and oil-fired versions are identical in construction, but the oil-fired one is

No! No! It's not just another HOIST

–IT'S PNEUMATIC–WITH THESE ADVANTAGES

- ★ *Low maintenance costs*
- ★ *Will withstand overload shocks*
- ★ *No fire hazard*
- ★ *Unaffected by extremes of temperatures and moistures*

There are many more advantages to be gained from using Globe pneumatic hoists than many people realise. All models have variable speed, are built to ensure a long trouble-free life, and are tested to a running overload of 50%. Why not investigate the advantages of Globe pneumatic equipment in your works. Our literature will give you full details.

The GLOBE PNEUMATIC ENGINEERING CO. LTD.

ASHTON ROAD, HAROLD HILL, ROMFORD, ESSEX
Telephone: INGREBOURNE 43851 5 lines

PLANT EQUIPMENT NEWS

fully automatic in operation, pressure being maintained constant within narrow limits over the full operating range of the boiler. With either version, a very high efficiency (of up to 80%) is claimed. **Cochran & Co. (Annan) Ltd., Annan, Dumfriesshire.**

BCE 8250 for further information

Split Body Single-seated Diaphragm Valve

This new valve has been developed by the Audco Annin Division of Audley Engineering Co. Ltd. at the request of instrument engineers in a wide variety of industries. It is intended to supplement the range of Audco Annin Domotor valves for the simpler applications which do not justify the use of a positioner. This model retains all the advantages of split body construction used with the Domotor operated valves, and sub-assemblies of body and actuator are interchangeable. Should a change of service justify the use of a positioner, it is possible to mount this on the top or side as desired. The valve body is produced in a variety of metals including cast iron, stainless steel and bronze, and is available in sizes up to 1 in., and will shortly be available in sizes up to 2 in. **Audley Engineering Co. Ltd., Eastern Avenue, Gloucester.**

BCE 8251 for further information

Impervious Graphite Entrainment Separators

The problem of separating entrained liquids from corrosive gas streams has been successfully tackled by means of impervious graphite equipment. Designed for high collection efficiency and low pressure drop, the corrosion-resistant modules of a new range of separators measures 1×2 ft and can be easily assembled into banks to fit any duct or process vessel. The separator modules are of unitised construction, and operate on the principle of impingement plus venturi action. Staggered rows of teardrop-shaped impervious graphite rods are cemented in place with a minimum of ¼-in. clearance to minimise clogging. The staggered arrangement prevents straight-through flow, and the open diagonal lanes permit easy cleaning when necessary. The streamlined rod shape retards re-entrainment and minimises resistance to gas flow. Modules are available in two styles: style A is used in single-row entrainment separators or as the top row of larger assemblies; style B (see illustration) units for the lower rows have a gutter and downcomer to provide positive drainage of the liquid separated from the gas by upper units. Side plates for both styles provide proper fit to the wall of the containing vessel. Approximate capacity of one module is the same as that of a 20-in. line-type entrainment separator. The number of modules required for a given application can be determined by dividing the total gas flow by the capacity of one module, obtained from a nomograph provided by the manufacturer. **The Carbon & Graphite Department, Union Carbide International Co., 270 Park Avenue, New York, 17, U.S.A.**

BCE 8252 for further information

Tablet Machine

The manufacturers of the Rotapress tablet machine, Manesty Machines Ltd., state that this new machine has been found to give exceptionally good results with a number of materials when compressing at high speeds; it has been found that some materials produce a very high grade of tablet even when the machine is running at its maximum speed.

Another feature of this machine is the compressing of material twice in the one machine, which has been found to obviate "slugging". This, however, halves the rated output and is not therefore suitable with all materials. **Manesty Machines Ltd., Speke, Liverpool, 24.**

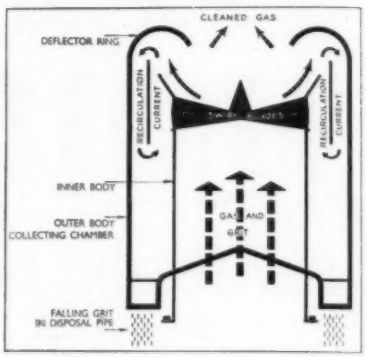
BCE 8253 for further information

Small Gas-fired Steam Boiler

The Gas Council has issued an appraisal of a new small steam boiler with a heat input of approximately 14,000 Btu/hr at a gas pressure of 1.0 in. w.g. Under such conditions, the evaporation rate was found to be 7.6 lb./hr from and at 212°F, while the thermal efficiency is 51.6%. The appliance has been designed as a self-contained unit operating at a pressure of approximately 60 lb./in.^{2} All controls are attached. The overall dimensions, including the controls, are 20 in. by 16 in. by 37 in. for the boiler. It is bolted to a cylindrical water tank mounted on swivel castors and having a capacity sufficient for 1½ days' normal working. The cylinder is 14 in. diameter by 27 in. in height, and is raised approximately 4 in. from the ground by the castors. Details are available in Report No. 711/59 of the Industrial Gas Development Committee of the Gas Council. **Vapor Vessels Ltd., 85 Overton Road, London, E.10.**

BCE 8254 for further information

Grit Arrester

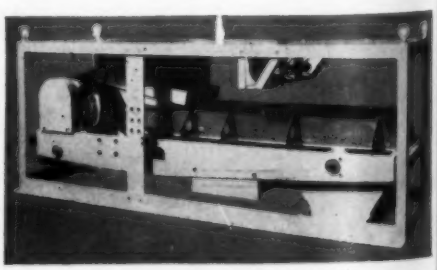


Charred paper and paper ash emitted from incinerators may be largely collected by using the Cory grit arrester. In spite of the low settling rate of the particles, the arrester has proved very successful, and has been proved capable of reducing the residual dust burden to an average concentration of 0.07 grain per cu. ft. Applied to a central heating boiler where oil smuts were being emitted, it was found necessary to include a water washer which was operated once a week. **Combustion Equipment Ltd., 61 Belsize Lane, London, N.W.3.**

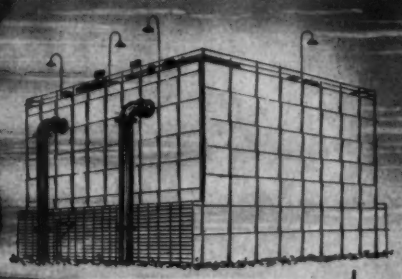
BCE 8255 for further information

Equipment for Proportioning Liquids and Solids

By means of a specially designed packaged unit, it is possible to proportion liquids and solids simultaneously. This equipment, developed by the Thirty Ninety Eight Co., not only permits the proportions of either to be altered at will, but it also allows the total discharge rate of the liquids and solids to be varied over a wide range without disturbance to the preset proportions. The illustration below shows the constant weight feeder suitable for most free-flowing materials. This is used with the drive-pump unit with two pumps and selector mechanism.



There is more than meets the eye in cooling tower design!

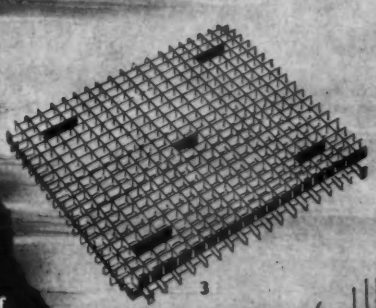


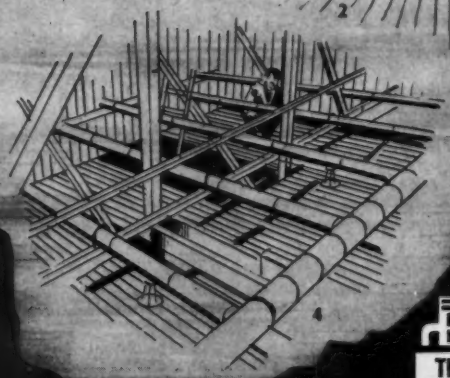
1 ASBESTOS SHEATHING This inherently fireproof material can enhance tower appearance.

2 PARABOLIC FAN STACK Provides maximum fan operating efficiency with maximum structural strength. Increases air volume by velocity pressure recovery and cuts h.p. requirements for a given performance condition.

3 POLYGRID PLASTIC PACKING Increases cooling capacity, reduces dry and wet operating weights. Ensures uniform distribution and greatly adds to tower filling life.

4 WATER DISTRIBUTION Totally enclosed to minimise algae, Timber pipes with porcelain or plastic nozzles cut out corrosion problems.





Their continuous policy of research and development into industrial cooling problems has produced further notable improvements which can now be offered with the Head Wrightson Fluor FP Series of Counterflo Induced Draught Cooling Towers. Tests under all conditions make it possible to give a comprehensive performance guarantee which rigidly defines minimum conditions of thermal operation in every tower supplied.

THE INDUSTRIAL COOLING ENGINEERS

Consult The Experts

HEAD WRIGHTSON PROCESSES LTD

London and Sales Office: 20/24 OLD STREET LONDON EC1

Head Office: The Friarage · Yarm · Yorks

Offices at P.O. BOX 1595 SYDNEY · P.O. BOX 1034 JOHANNESBURG · P.O. BOX 2608 CALCUTTA AND P.O. BOX 706 HAMBURG

Associates in the U.S.A., The Fluor Products Co., Los Angeles 22, New York, Chicago, Boston, etc.

P 3540

PLANT EQUIPMENT NEWS

The solids are proportioned by means of a balanced belt type of constant weight feeder; deviation of the balance beam is automatically compensated by the action of a servo-operated feed gate fitted to the intake hopper. The feed rate is adjusted by changing the belt speed, the belt itself being driven by a Selsyn receiver, the transmitter being fitted to the main driving system of the pump.

For the proportioned liquid supply a positive variable-displacement pump is provided. This is coupled to a reduction gear which in turn is coupled to a Carter infinitely variable speed gear which receives the drive from the prime mover. If more than one pump is included in the unit, the reduction gear is coupled to a countershaft instead of direct to a pump. The output shaft of the variable gear is connected to the Selsyn transmitter mentioned above. The speed control of the variable speed motor is fitted with a servo motor and chain drive so as to provide automatic and remote control.

If a single pump and feeder are used together, two adjustments only need be made. The total rate of delivery of solids and liquid together is determined by the setting of the variable speed gear and the proportion of liquid to solid is determined by the adjustment of the pump stroke. Change in speed control changes both pump and feeder so that the correct proportions are maintained. Normally this equipment can be supplied with capacities up to 20 tons an hr, of which 25% can be liquid; units with greater capacities can be provided to special order. **The Thirty Ninety Eight Co. Ltd., Gatwick House, Lowfield Heath, Sussex.**

BCE 8256 for further information

High-speed Vibratory Screens

A wide range of materials can be handled by a new design of vibratory screen known as the Viking-Grantham which is fitted with a high-speed vibrator unit. The latter consists of a motor incorporating as an integral part a drive and vibrator, thus dispensing with the conventional out-of-balance shaft requiring heavy bearings and "V" rope drive. This simplifies the design and reduces the horsepower required. Amplitude of vibration and the angle of deck are both readily adjusted. The latter may be set at angles from 5° to 30°. Single- and double-deck models are at present available in two sizes. The smaller has a tray 4 ft long by 2 ft 7 in. wide and the larger a 5 ft long tray 3 ft 7 in. wide. **W. J. Jenkins & Co. Ltd., Retford, Notts.**

BCE 8257 for further information

New Dust Extractor

The dust-laden gas is passed downwards through a four-chamber vessel in which it is first saturated with steam or water then its velocity is increased and its pressure is reduced and finally after a further saturation the dust is collected in a trap. This dust extractor is said to continuously recover dust particles down to 0.03 μ in size. It is working satisfactorily in cement and sulphuric acid plants, where over 99% of fine dust particles down to 0.03 μ are successfully recovered. **Socomath S.A. Lyons, France.**

BCE 8258 for further information

Valves

Among the valves shown at the recent Instrumentation, Electronics and Automation Exhibition were a number of diaphragm types suitable for automatic control equipped with power actuators.

A case was a Saunders valve fitted with a Rotork actuator (type 12 B, Mark 2) which is fitted to valves of this make for sizes of 2 in. to 5 in.

The emergency hand-wheel is operated with interlocked wedge lever which disengages the motor drive before the hand-wheel can be engaged. In addition, a mechanical valve position indicator is fitted and the actuator can be arranged for control by contact or trip reversing starter. Power supply is normally 400/440 bolts 3 ph 50 cycles.

Other valves in the range can be supplied with different sizes of actuator. **Saunders Valve Co. Ltd., Cwbran, Monmouthshire.**

BCE 8259 for further information

Colorimeter

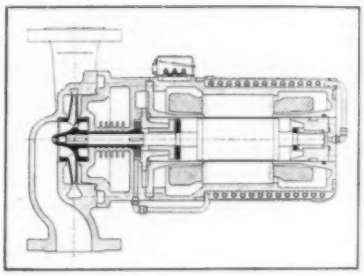
In a new instrument for colorimetry called the Spectra, a single photocell is employed at all wavelengths and no amplifier or internal batteries are needed. The manufacturers announce it as combining the simplicity and convenience required for routine colorimetry with the extra versatility and high performance required for research. In it a high quality continuous spectrum wedge having a bandwidth of 30 mμ gives accurate wavelength selection over the range of 400-700 mμ. The illuminated wavelength dial is individually calibrated in divisions of 5 mμ. In use, light from a pre-focus lamp passes through a heat-absorbing filter and condenser lens assembly to focus on a slit in front of the continuous spectrum wedge. A cylindrical lens is interposed between the wedge and sample and serves to restrict the vertical spread of the beam. Transmitted light from the sample is collected by a barrier layer photocell which is coupled to a built-in taut suspension galvanometer fitted with zero and clamping controls.

The instrument is housed in an aluminium case, 18 in. × 9 in. × 8 in., durably finished in grey hammer stove-enamel. Sample solutions are contained in either fused glass cells or test tubes, which are mounted on a sliding carriage moving between stops. The instrument weighs 19 lb. 10 oz. (8.9 kilos) and is designed for normal use on 230 volts 50 cycles a.c. mains unless otherwise requested. It has been applied for analysis of metal alloys, trace metal determination in water treatment and for control purposes at sewage works. **Evans Electroselenium Ltd., Halstead, Essex.**

BCE 8260 for further information

Glandless Pumps for Chemicals

A new series of canned rotor pumps suitable for a variety of applications requiring freedom from leakage are now being marketed in this country by Mason & Morton. Originating from a central heating circulation pump, these pumps are suitable for volatile, corrosive, and radioactive liquids at temperatures up to 400°C and static pressures up to 50 kg/sq cm. Typical applications include the pumping of nitric acid, liquid ammonia, dowtherm, and hot oils.



The first model in the range is suitable for temperatures up to 100°C and static heads up to 6 kg/sq cm. In this model the protective can for the motor is sealed at its ends by synthetic rubber gaskets. Materials of construction include cast iron, gun-metal, aluminium, stainless steel, and the journal bearings may be made from gun-metal, synthetic resins or carbon. This model is essentially for light duties. Another model is suitable for temperatures up to 130°C and static heads up to 10 kg/sq cm. In this case the pump is constructed from 18/8/2.5 Mo stainless steel, but other alloys can be employed if required. In this case the rotor sleeve is welded to the ends of the pump; and for bearings carbon, synthetic resins and PTFE can be used.

The third pump in the series is suitable for temperatures up to 400°C and static pressures up to 50 kg/sq cm. In this pump notable features are the separation of the motor from the pump by means of a lantern piece and the use of a small auxiliary impeller for circulating lubricating liquid through coils arranged in a water jacket for cooling the motor. A useful point is that motor windings can be changed without either emptying the

BCE 8194 for further information

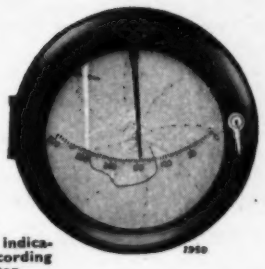
EASY TO READ...EASY TO FIX...

Cambridge

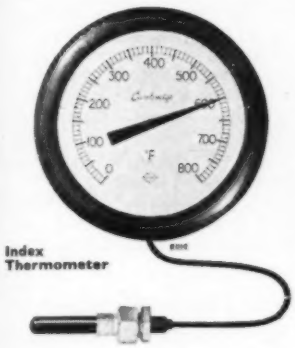
THERMOMETERS AND THERMOGRAPHS

with MERCURY-IN-STEEL systems

for temperatures from −20°F. to 1,000°F. (or −30°C. to 600°C.)



Combined Indicating and Recording Thermometer.



Index Thermometer

INDEX THERMOMETERS

as illustrated, are made in 3 dial sizes—4″, 6″ and 8″—and are available for proud or flush mounting. Boldly marked linear scales facilitate easy reading and each thermometer is guaranteed accurate to within 1% of its range. The adoption of standard patterns and ranges enables many types to be available for immediate delivery. These instruments are robust and long-lived.

THERMOGRAPHS

as illustrated, are available in standard ranges for all requirements. Of robust construction, they record accurately and clearly on 10″ circular charts. Two-pen instruments are available for recording, on the same chart, temperature and pressure, or wet and dry bulb temperatures for humidity readings. All models may be either proud or flush mounted.

Send for LIST AR. For future publications ask for Mailing Form AR/9/60

CAMBRIDGE INSTRUMENT COMPANY LTD., 13 Grosvenor Place, London, S.W.1

ULTRASONICS LTD.

This ultrasonic homogenizer offers the easiest, most convenient and efficient way of making emulsions and dispersions.

Minisonic Model 3 is made in stainless steel with built-in glass vessels and perfect finger tip control valve.

Developed on the experience of over a thousand installations of the Rapisonic, it is an advanced and reliable machine, sold at a sensible price.

Details on request from *Ultrasonics Ltd.*, Westgate, Otley, Yorkshire.

THE NEW MINISONIC

model 3

BCE 8195 for further information

PLANT EQUIPMENT NEWS

pump or disturbing the pump connections. Capacities range from 0.3 to 40 litres per sec., depending upon speeds of rotation which may be 1450 or 2900 rpm. **Mason & Morton Ltd., 3-5 Vandon Street, Buckingham Gate, London, S.W.1.**

BCE 8261 for further information

Clarification Filter

A filter recently introduced to the British market has a number of advantages over existing clarification equipment.

It is possible to use all the conventional types of filter-aids such as kieselguhr, and the equipment can be supplied in various materials of construction. In essence, it consists of a pressure vessel with a filter assembly made up of a number of filter elements attached to a vertical perforated rotatable shaft. Distance pieces fitted on the shaft ensure the proper alignment of the plates. The filter medium can be either stainless steel or cloth-covered screens, with the pre-coat lying horizontally on the upper side of each filter element. For this reason, shedding of the pre-coat, as can happen with other systems, is rare with this filter.

After a filtering operation, the vessel can be emptied either by filtering through the lowest element (the other remaining elements being closed by means of a valve) or by means of a discharge fitted on the vessel base. By rotating the vertical shaft (which is motorised) cleaning is carried out by centrifugal force; at the same time wash water can be introduced via the shaft on to the filter elements, the entire process of cleaning taking no more than a minute or two.

The advantages can be summarised—elimination of manual operations, cleanliness since the filter need not be opened for cleaning, and ease of automatic sequence operation. Further, when filter cloth is used the filter can be kept closed during all phases of operation. **Mason & Morton Ltd., Murray House, 3-5 Vandon Street, London, S.W.1.**

BCE 8262 for further information

Bellows Expansion Joint

A bellows expansion joint known as the the Genflex has been introduced by Vokes Genspring Ltd. to absorb the expansion and contraction of pipe systems owing to temperature changes, as well as for applications in shaft seals, packless glands, expansion pockets, packless valves and flexible joints.

The standard model is produced from 18/8 cold-rolled stainless-steel sheet, welded into a tube with a longitudinal butt weld under accurately controlled conditions. Convolutions are produced without any circumferential welds. For special applications, they can be made from Nimonic 75 for temperatures over 750°C, and Monel, Inconel and titanium where unusually corrosive conditions occur. Rectangular and other special bellows can be fabricated to large sizes. Diameters above 120 in. bore can be produced to order. Units are available with all patterns of restraint such as hinged, gymbal, tied or articulated and with any type of coupling. **Vokes Genspring Ltd., Henley Park, Guildford, Surrey.**

BCE 8264 for further information

New American Adhesive

The Rubber and Asbestos Corporation are now marketing the Bondmaster G 523 series of adhesives which are most suitable for tank lining applications. The new plastic has been developed by the Hercules Power Co., and is a high-bond-strength, non-curing, room-temperature-contact-bonding, liquid adhesive for rigid and semi-rigid materials. It is suitable for application to decorative laminates, linoleum, metals, most plastics (except plasticised vinyls), some rubber stocks, wood, plaster, composition board, leather, foam and sponge rubbers, polyurethane foam, etc. **Omni (London) Ltd., 35 Dover Street, London W.1.**

BCE 8265 for further information

New Publications

The Lapp Pulsafeeder is a machine designed for handling corrosive and non-corrosive liquid chemicals. It is a pump that will take liquid from storage and transfer it against pressure, a chemical feeder operating at a set rate and a meter. It is also a means for fluid flow control of a filling machine, a proportioner and a sampler. Finally, it may also be operated as a gas compressor. A new Sales Catalogue 59 is now available to describe the equipment. **Process Equipment Division, Lapp Insulator Co. Inc., Le Roy, N.Y., U.S.A.**

BCE 8266 for further information

Instruments for resistance measurement, laboratory and industrial pH meters and analytical apparatus (sonic gas analyser, titrimeter) and laboratory standard instruments are listed in 'Measuring Instruments for To-day and To-morrow", a new brochure by **Electronic Instruments Ltd., Richmond, Surrey.**

BCE 8267 for further information

Technical principles underlying automatic chlorination are described in two recent publications from the leading Company in this field. The first deals with an automatic chlorine residual controller, and outlines the applications for this system in a number of fields. One of the main features of the equipment is that it feeds chlorine to a desired level irrespective of changes in flow of the liquid being treated. These include the treatment of process water in food industries and condenser cooling water for power stations. The second pamphlet describes instruments for the continuous measurement and recording of residual chlorine in water. **Wallace & Tiernan Ltd., Power Road, Chiswick, London, W.4.**

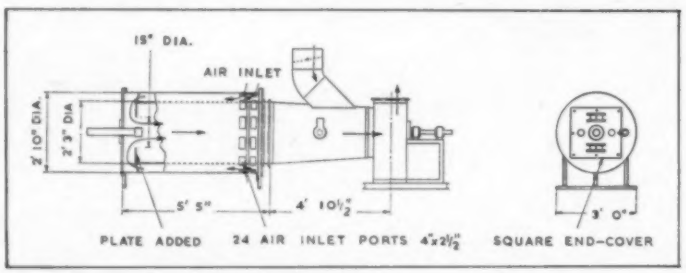
BCE 8268 for further information

Direct-fired Air Heater

The North Thames Gas Board have carried out performance tests on a direct-fired air heater (Report No. 721/60 of the Industrial Gas Development Committee of the Gas Council). In this unit, the heating section consists of two concentric cylinders, the outer being closed at one end by a plate with the annulus closed at the opposite end. The inner cylinder forms the combustion chamber using a size 2500 Hypact burner, with ignition and flame-failure probes. Air enters the annulus near the closed end through twelve rectangular holes around the periphery and passes first towards the back of the heating section, across the external surface of the inner cylinder, then into the combustion chamber and in the reverse direction towards the fan. A vane-type air flow switch is fitted to this section to provide protection against fan failure.

On test, this heater proved to have a maximum output of air from the heater of 133,000 ft³/hr at 626°F, while the gas rate at 1 in. w.g. burner pressure was 3000 ft³/hr. The heat output was calculated to be 1,468,550 Btu/hr and the thermal efficiency of the heater 99.2%. Finally, it was noted that the inner mild steel cylinder did not exceed a safe temperature. **Heat & Air Systems Ltd., 172 Buckingham Palace Road, London, S.W.1.**

BCE 8263 for further information



How much skill makes 30 tons?

Approved by Lloyds for Class II welding for pressure vessels.

The skill that goes into our special castings is something quite unique and immeasurable. Customers assess it in terms of quality, finish and precision—and come back for more! They include many of the largest chemical engineering and industrial organisations in the country. We cast in iron, and all ferrous alloys, and can fabricate in mild and stainless steels to your most exacting requirements.

WIDNES Foundry & Engineering Co. Ltd

Established 1841

Lugsdale Road, Widnes, Lancs.

Phone: Widnes 2251/4 & 2889 Grams: 'Foundry Widnes'

W 59

World of Chemical Engineering

Du Pont in Northern Ireland

At Maydown, Londonderry, Northern Ireland, is to be found yet another sizeable chemical plant, for towards the end of last month the Du Pont neoprene plant was officially opened. At present the main product is to be neoprene although other acetylene-derived materials may emerge from the plant in the future. The new plant, costing about £4,000,000, has an output of 50 million pounds of neoprene and latices, the acetylene for the three-stage process being supplied from the adjacent Carbide Industries plant.

In the process, acetylene is converted catalytically (a copper catalyst is employed) to monovinylacetylene, and this intermediate, after purification by distil-

lation, is reacted with hydrogen chloride to form chlorobutadiene, which, on polymerisation, yields the elastomer.

Of interest is the refrigeration plant consisting of the two largest ammonia units installed in the United Kingdom; a separate plant provides the nitrogen required for preventing air contamination, and the hydrogen needed for the preparation of hydrochloric acid is obtained by reforming propane. Chlorine is transported in 200 ton lots from the I.C.I., Runcorn, and is unloaded by nitrogen pressure into storage tanks of 700 ton total capacity.

To prevent contamination by the liquid effluent discharged to the Foyle River extensive facilities have been provided. These include two burners for organic wastes.

Heat Transfer Conference

Buffalo, N.Y. was the venue of another important August Conference, the organisers in this case being the A.S.M.E. and the A.I.Ch.E. and the subject Heat Transfer. The large number of papers ranged over a wide field and a valuable feature was the inclusion of open discussion panels. One of these, with D. Q. Kern as the Moderator, probed that ever-recurring problem, the discrepancies between designed and actual performance, one of the aims of this discussion being to improve the liaison among operations, design development, and research.

Other open panels discussed cryogenic heat transfer and heat exchanger standardisation. As for the papers, these varied from those with an analytical or research character to those concerned directly with the design of heat transfer equipment. At least two papers reported upon increased free convection transfer rates produced by the influence of sound waves. Analytical papers were concerned with such matters as laminar natural convection, heat transfer to non-Newtonian fluids, laminar film condensation to flat plates, single and multiple horizontal tubes, and the melting of semi-infinite slabs.

The subjects of papers with a clear design interest included the efficiency of finned annular passages, with fins attached to both inner and outer walls of the inner tubes, the performance of extended surfaces in the presence of humid air, and a procedure for the design of equipment for the economic drying of moist solids.

Heat transfer to particulate solids also received attention from several authors. One paper presented a review of fluid-to-particle heat transfer in packed and moving beds, another showed how to estimate equipment size for the heat processing of solids in the fluidised state, while in the field of heat transfer to porous masses, one author examined the soundness of the assumptions of negligible conduction in the direction of flow and negligible resistance to heat transfer between fluid and solid. Another paper provided correlations for determining the radial effective conductivity of packed beds; in this paper the solid conduction mechanism was shown to be independent of fluid Reynolds Number.

Finally, mention must be made of a paper given by H. S. Mickley (*et al.*) on the relation between transfer co-efficients and the thermal fluctuations in a fluid bed, and which showed how to calculate the heat transfer from tubes placed in fluid beds.

New Sludge Digestion Plant

Mr. Henry Brooke, Minister of Housing and Local Government, opened a new sludge digestion plant at Minworth, Warwickshire (Birmingham, Tame and Rea District Drainage Board), on June 17. The new plant will reduce filth and pollution and enable the fish to return to that part of the river. It comprises 16 digestion tanks with four control chambers each placed centrally in a group of four digestion tanks; interconnecting subways; a main pumphouse and a small subsidiary high-pressure pumphouse; together with ancillary mechanical and electrical equipment. Pending the construction of the sedimentation plant at Minworth, only 12 of the digestion tanks are fitted with gas collectors, the remaining four tanks being used for the reception and dewatering of the crude sludge from Saltley, Ashold and Tyburn Works. The gas collected will be used during the interim in 12 gas-fired sludge heaters. A surplus gas burner is provided. Ultimately all the tanks will be equipped for the collection of gas, which it is anticipated will be used as fuel in engine-driven electricity generating sets housed in a station adjacent to the digestion plant. When the generating station is in operation, sludge heating will be effected by the use of waste heat from the engines. In order to conserve heat, the digestion tanks have been banked around and the site finished at tank coping level.

New Acetic Acid Plant

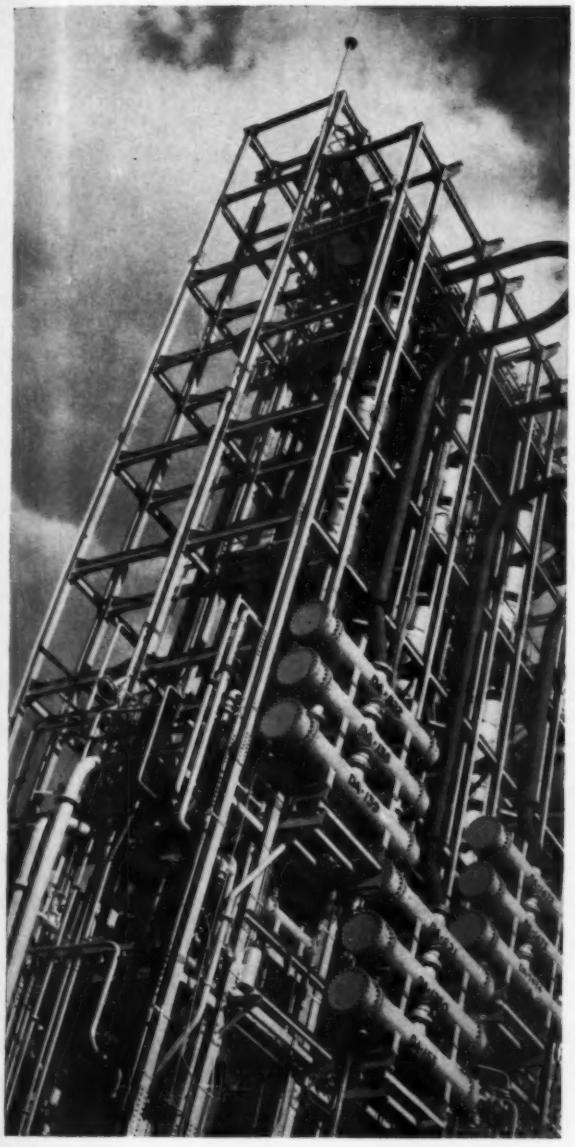
The Distillers Co. Ltd. have announced that they are building a new £2 million acetic acid plant at their Hull works, using a process based on direct conversion to acetic acid of a readily available petroleum hydrocarbon feedstock. In their announcement, the company point out that all classical routes to acetic acid (apart from the acetic fermentation process) involve the oxidation of acetaldehyde, derived from acetylene, ethylene or ethanol formerly produced from coal or by fermentation, and nowadays from hydrocarbons. The new development by D.C.L. is unique in that it achieves the direct production of acetic acid from the same basic readily-available hydrocarbons which are commonly used today for producing acteylene or ethylene, thus avoiding the isolation of these intermediates. The acetic acid which is the main product of the process can be made to very strict specifications. In the process, minor amounts of formic, propionic and succinic acids are also produced.

Nitric Acid Plant Changeover

In mid-July Ardeer was the scene of another I.C.I. development, the start-up of the new medium pressure nitric acid plant which replaces the atmospheric pressure and the high pressure ammonia oxidation plants formerly operated at the factory.

From the description of the unit now available the impression is given of a conventional process which employs the best practices of existing similar processes, particular attention having been paid to the recovery of energy, with the result that plant in this respect is self-supporting.

The oxidation reaction takes place at 850°C. upon a Pt-Rh catalyst, and heat is recovered from the reaction gases by waste heat boilers which supply steam at 270 psig at atmospheric pressure. This steam is fed to the turbines driving the 2000 hp centrifugal six stage compressor installed for raising the gases to the absorption pressure. Additional energy for driving the compressor is supplied from an expansion turbine from the absorber exhaust. A feature of the absorption system, which operates at 42 psig is the heat exchange circuit employed for the gases entering and leaving the absorber system.



PROTECT CHEMICAL PLANT AND MACHINERY WITH . . .

"EPINAMEL"

ANTI CORROSION COATINGS

This illustration, reproduced by permission of Shell Chemical Co. Ltd., presents a typical example of the successful application of Epinamel Anti-Corrosion Coatings to Chemical plant.

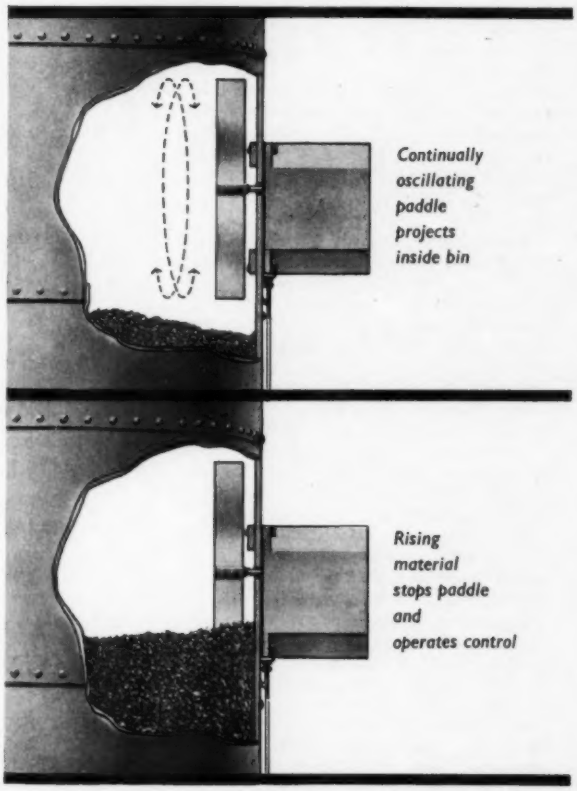
Write for full details of Epinamel to :

ARTHUR HOLDEN & SONS LTD.
BORDESLEY GREEN ROAD, BIRMINGHAM, 11
TELEPHONE : VICTORIA 2761 (5 LINES)

Keeping careful check on bin levels

The Bindex is a pneumatic bin-level controller—simple, sensitive and thoroughly dependable.

Projecting inside the bin is a paddle which oscillates with a continuous see-saw motion. This movement is hampered when the bin contents reach the paddle and a pressure switch is immediately activated to operate an alarm and initiate controlling action.



- The Bindex is driven by compressed air, a major advantage when electric circuits are undesirable.
- It operates with granular and lumpy materials, with cohesive powders such as flour and cement, and with liquids.
- It is inexpensive, quick to install and simple to maintain.

Please send for leaflet MSD/2

SIMON INDUSTRIAL PLANT

HENRY SIMON LIMITED, CHEADLE HEATH, STOCKPORT.
Telephone: Gatley 3621. Telex 66-287.
HS356

Low Temperature Conference at Boulder

The sixty or more papers presented at the Cryogenic Engineering Conference just concluded at Boulder, Colorado include a number of interest to chemical engineers, these falling within the categories of APPLICATIONS, PROCESSES, TRANSFER PHENOMENA, EQUIPMENT, HEAT TRANSFER, MECHANICAL PROPERTIES and PHYSICAL EQUILIBRIA.

Among the APPLICATIONS papers was one reporting details of new refrigeration systems employing Joule-Thomson expansion and nitrogen-hydrogen and nitrogen-neon mixtures as the refrigerant. (J. M. Geist and P. K. Lashmet.)

In the same grouping was a paper giving details of a new refrigeration system capable of supplying cold continuously at 4.2°K. This new system, although pistonless, achieves the effect of several expansion engines and it requires gas at 300 psia only. (W. E. Gifford and T. E. Hoffman.)

Among the papers on PROCESSES were two dealing with liquid hydrogen; one provided details of its manufacture from refinery waste gas (P. D. Fuller and W. E. Gifford) whereas the other dealt with explosion hazards (M. G. Zabetakis, A. L. Furno and G. H. Martindill.)

Various problems were considered in the series of papers devoted to the transference of cryogenic fluids. One paper presented an analytical method for estimating the gas required for pressurising vessels containing liquids such as hydrogen, oxygen, fluorine, neon and so on, that are equipped with a diffuser to prevent direct jetting of the gas into the liquid. (D. C. Bowersock and R. C. Reid.)

The use of a computer for investigating the effect of withdrawing a liquid where reliance is placed upon gas pressure transfer was outlined by J. M. Canty; and another author showed how to estimate the pressure change taking place in a vented tank being filled with liquid oxygen. (D. G. Burkhard and others.)

Finally, within this section was a paper on the vacuum insulation of pipework systems which included a description of a vacuum system including its design, dimensions and performance.

In the section devoted to PHYSICAL EQUILIBRIA the papers presented dealt with such topics as the predicting of gas phase compositions in pressurised binary systems containing a pure condensed phase. (B. S. Kirk). Another paper gives information for the design of silica gel adsorbers for purifying petroleum by-product hydrogen (M. J. Hiza).

In the field of HEAT TRANSFER of particular interest was the paper presented by D. E. Ward of the British Oxygen Engineering in which he provided heat transfer and pressure drop data for metallic and stone regenerator packings.

Other authors dealt with heat and mass transfer, to uninsulated L.O. containers. (D. C. Holten); two-phase flow of an evaporating liquid through a horizontal tube (K. E. Leonhard); and a study of heat transfer to boiling liquid hydrogen. In this latter paper local and overall heat transfer co-efficients are presented for liquid hydrogen flowing through a heated tube. In the work described pressure varied from 30 to 70 psi and the temperature differential ranged from 50 to 1000°F. between fluid and wall. (R. W. Graham and others.)

New Weed Killer Plant

What may become ultimately one of the largest agricultural chemical factories in Europe has just been completed by Dow Agrochemicals Ltd. at Kings Lynn, Norfolk. The new factory, costing one million pounds, has been completed two months ahead of schedule by Constructors John Brown Ltd. and the main product is to be Dowpon, a systemic selective weed killer, the manufacture of which in Britain offers considerable economies in crop-spraying and in many areas is likely to eliminate the manual removal of weeds.

In its basic design the plant bears a resemblance to a similar Dow plant in the U.S.A. However, the design of the British plant, supervised and controlled by Mr. J. W. Warburg, the chief engineer of Dow Agrochemicals Ltd., does incorporate a number of detailed novelties.

Fertiliser and Related Plants

A number of developments have been reported in the fertiliser field. Thus a £1,000,000 expansion is to be made to Fisons fertiliser plant at Immingham, Lincolnshire. This will provide a substantial increase in phosphoric acid output towards June of next year. The plans for expansion include the manufacture for the first time, of ammonium phosphate, following modifications to the triple superphosphate plant. The new product is to be distributed among Fisons' other fertiliser plants for use in high analysis fertiliser.

A 380 metric tons per day sulphur-burning sulphuric acid plant is to be erected at Ptolemais in Greece, as part of a large nitrogenous fertiliser factory. The plant is to be built and designed by Chemical Construction (G.B.) Ltd. who will also supervise the initial commissioning of the unit.

Another award to the same company is for a sulphuric acid and single superphosphate plant to be built for Adarsh Chemicals & Fertilizers Limited, Bombay, India. The units will be in operation in 1961 and the sulphuric acid output, based upon sulphur dioxide derived from sulphur, will have a capacity of 50 tpd whereas the fertiliser output will be 6-10 tph.

M. W. Kellogg Company (New York) have been awarded a contract by Solar Nitrogen Chemicals Inc. for a second ammonia plant.

The new plant, to be constructed near Joplin, Missouri, will produce 300 tons per day of ammonia and will be based upon Kellogg steam-methane reforming process according to which anhydrous ammonia is produced from natural gas, steam and air. The first stage of the process will be the removal of sulphur from the natural gas to prevent catalyst poisoning. The steam-gas reforming operation takes place in two stages to produce hydrogen, carbon dioxide and carbon monoxide. This mixture of gases is then passed through a reactor in which most of the carbon monoxide is converted to hydrogen and carbon dioxide.

The raw synthesis gas, that is the hydrogen nitrogen mixture, plus carbon dioxide and some carbon monoxide, is compressed and purified; first by monoethanolamine to remove carbon dioxide (at 375 psig) followed by treatment with cuprous ammonium acetate for removal of carbon monoxide and traces of carbon dioxide. This final treatment is carried out at 2155 psig. A final washing in caustic soda solution removes the remaining traces of carbon dioxide.

The purified synthesis gas at 4700 psig is converted to ammonia by means of a system of two converters operating in parallel employing an iron catalyst.

Titanium Oxide Plant to Extend

In their annual report Laporte Industries Ltd. give prominence to a number of developments. Thus, Laporte Chemicals Ltd. have designed and erected a new plant for the manufacture of sodium chlorite and have extended the laboratories at the Baronet Works, Warrington (cost £48,000) with the aim of improving process control. Laporte Titanium Ltd. are increasing their capacity at Stallingborough from 30,000 tons per annum to 50,000 tons per annum of titanium oxide, the total expenditure involved being 3½ million pounds. The same Company is to manufacture titanium-nickel yellow and a range of special products for the ceramic industries, while in the background some interesting developments are forecast in the field of organic titanium compounds. In the case of Laporte Acids Ltd. the acquisition of Glebe Mines and James Wilkinson & Son Ltd. signals the entry of the Company into the field of fluorine chemistry.

Fabricating Facilities

Henry Balfour & Co . Ltd., of Leven, Fife, who opened their new laboratories and research centre in May last are to proceed with a major expansion of manufacturing facilities. They will build a new 24,000 sq. ft boiler shop, costing £250,000 and other ancillary units, costing in all £500,000. This development at Mountfleurie will supplement the older Durie Foundry work where expansion and development plans are also in hand. A very big extension to the enamelled products department has been approved and other developments are forecast.